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(54) Title: ECONOMICAL SKIN-PATTERN-ACQUISITION APPARATUS FOR ACCESS CONTROL; SYSTEMS CONTROLLED THEREBY

(57) Abstract

Surface relief of a finger etc. is read using an optical-fiber prism unit, with fiber terminations at one end to contact the surface, and at the other for light passage along fibers from the first. Light enters where NA < 0.5 and fiber diameter is constant with longitudinal position, to light the first-end terminations. For each fiber a light fraction dependent on surface relief reaches an electrooptical unit at the second end to form an electrical signal. A focal system relays light to the electrooptical unit, forming a 1/3 image of the second end. This system has an imaging objective ($\underline{f} \cong 8$ mm), and a field lens (40 mm) formed or fixed at the second end to flatten the focal surface and the lighting. The device is in a 1.4 - 2 L case, with a battery or power input, skin reader to form a data array matching the skin pattern, converter to form a corresponding data array for verifying, digital signal processor to do the verifying, output to indicate or implement a decision; apparatus to format data in compact form (level-downsampled, e.g. mapped into 2- or 1-bit data) for storage, import or export; and apparatus to convert the data from that form to a different form (multilevel, or as sinusoids or Fourier transforms) to use in verifying. A video controller (with custom-programmed logic circuit) operates the sensors to develop the data array; an ADC digitizes the array; memory holds an authorized-user skin-pattern template, firmware for the processor, and data used in verifying; an output register holds the decision signal - all on a control, address, and data bus. High-power, radiative elements and a fast high-impedance data reader are on a common board in an isolating layout. Sensor integration time is servoed for best contrast. An optical bench has prism-mount bosses, an objective mounting ring, and a sensor-array mounting pocket. The prism unit is cylindrical, held by a cylindrical-section cradle fixed to the bosses and forming a novel condenser lens to support lights and couple light to the prism. The imager has a cylindrical wall, transverse face for output of a skin pattern, and angled elliptical face to contact skin. To make many optical-fiber prisms each with one transverse and one angled face, transverse and angled cuts through a fused-fiber cylinder are alternated. The verifier can be within, and respond to the analysis to control, a door handle or lock: a hand need not move from reading position to open the door.

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ECONOMICAL SKIN-PATTERN-ACQUISITION APPARATUS FOR ACCESS CONTROL; SYSTEMS CONTROLLED THEREBY

RELATED PATENT APPLICATIONS

Two coowned patent documents of Areté Associates, Inc., are wholly incorporated by reference herein: PCT/US96/01615, based on a U. S. application of Bowker and Lubard; and copending attorney docket xAA-37, filed in the PCT concurrently herewith on September 8, 1997, based on a U. S. application of Thebaud (teaching and claiming apparatus and method for analyzing skin patterns and verifying identifications on the basis of such analysis) later made PCT/US97/____.

FIELD OF THE INVENTION

This invention relates generally to automatic acquisition of skin-patterns (such as fingerprints), and other relieved-surface images, for access control — and to systems whose access is controlled by such automatic fingerprint etc. acquisition. The invention relates more particularly to fiber-optic prism systems for such fingerprint acquisition, and to cooperating mechanical and electrical provisions for both enhancing the identity confirmation and deterring circumvention of the identity confirmation.

Systems to which access is controlled in accordance with the present invention include personal weapons, other apparatus, facilities, financial services and information services.

BACKGROUND OF THE INVENTION

Very extensive discussion of the prior art appears in the Bowker document, mentioned above, and is earnestly commended to the attention of the reader. That discussion includes in particular a summary of previously known fingerprint techniques employing either frustrated total internal reflection (FTIR) or fiber-optic prisms. Familiarity with that presentation is assumed here.

In that document it is also taught that light should be injected into a fiber prism at a point where fiber diameter is sub-

stantially constant with longitudinal position and numerical aperture is less than one-half and preferably around 0.35; and also that a sensor is advantageously mounted directly to the prism means — either directly to a primary prism that receives the fingertip whose pattern is to be analyzed, or directly to a fiber-optic taper that reduces the fingerprint image size for use with a much smaller sensor. These two forms of the sensor mounting taught in Bowker represent tradeoffs of the relatively high costs of both sensors and tapers.

As pointed out in that document, the present price of even a relatively small detector if implemented as a conventional charge-coupled detector (CCD) array, is high enough to constitute the major cost element in apparatus according to the invention. A larger detector — the size of a fingerprint image — is prohibitively expensive for most applications.

This is the motivation for considering tapers even though a taper in turn disadvantageously adds to the weight, size and cost of the apparatus. At the time of writing of Bowker, however, the CCD cost advantage in provision of a taper in many cases was more than offset by the incremental cost of the taper — even without considering the weight and size penalty.

At that time, it was not possible to predict reliably whether eventual cost relief should be expected in the detector or in the taper, or in neither. Unfortunately at the present writing, more than a year and a half later, that situation has not changed.

Accordingly for most miniaturized applications the tradeoff solutions taught in Bowker remain uneconomical. It is still anticipated that those solutions will in time become practical, as the price of conventional crystalline-silicon CCD arrays in this size range may fall — perhaps partially in response to competition for usage in apparatus according to the present invention — or an alternative optical detector, such as for instance a self-scanned diode ("SSD") array or thin-film (noncrystalline) photosensor arrays, may become available at significantly lower cost.

Meanwhile a practical package embodying the better-illuminated fiber-optic prism taught in Bowker has not appeared, heretofore.

Self-contained print verifiers — While many fingerprint analyzers are available in desktop or countertop modules, no prior art teaches a satisfactory fingerprint reading and analyzing appara-

tus that is self contained (which, for purposes of this document, is to be understood as meaning at least self contained except for power source). Such apparatus is a necessary first step toward real-time fingerprint verification systems operable within either hand weapons or other tightly constrained volumes such as mentioned below.

Extremely small, self-contained print verifiers present special challenges: extremely high optical, electronic and logical precision are required in a tiny but rugged system — at very low price. These challenges have not been adequately addressed in the art.

Data isolation and incompatibility — A special problem of such self-contained systems is how to make the greatest use of data. This issue arises because system operations include taking original data, both from authorized users and candidate users.

In either of these cases, information about the fingerprint that has been read by the apparatus may later be needed or desirable for other purposes. Such use was previously suggested in connection with anamorphism in the data.

First, where a home or business has many locks, it may be desirable to take authorized-user data just once — using just one of the locks — and then electronically copy the information into all the others. Second, law-enforcement agencies may have a particular use for such data.

This latter situation may arise for example when a facility has been entered forcibly and there is reason to believe that the intruder first attempted to operate the fingerprint-controlled lock. It may also arise when a person who has been an authorized user steals from the controlled facility, or commits some other crime — whether there or elsewhere. Other possibilities arise when an authorized user, for example a missing child, is not likely to have been otherwise fingerprinted.

Data export can be a problem in particular when a system operates using multilevel data, or using data in a special form such as sinusoidal or Fourier-transform data — as is the case for instance with Thebaud's, mentioned previously. Exporting such data may not be useful if the receiving application (such as law enforcement) that could use the underlying information operates on data in more-conventional formats.

<u>Door applications</u> — While addressed broadly to many applications of a fingerprint reading device, <u>Bowker</u> gives particular attention to the configurations suited for use in guarding a weapon — particularly a small hand weapon. Mainly because of the cost considerations discussed above, hand-weapon applications appear to remain for the present just slightly beyond the range of economic development in commercial exploitation.

A market that is much more practical in view of the apparatus <u>sizes</u> that can be installed, and also taking into the number of now-unguarded units in use, is the protection of doors — and more particularly door handles. Although still small, a typical door handle and its associated lock have (at least potentially) several times greater volume for installation of security equipment than does a typical hand weapon.

Accordingly it is believed that the prior art has not adequately attended the opportunities for optical skin-pattern readers in direct association with doors, door handles and doorknobs.

<u>Numerical aperture of tapers</u> — In <u>Bowker</u> it is taught that a taper used in the invention should be of relatively very high NA, certainly well over 0.5, to compensate for the intrinsic degradation in light-transmitting power associated with the image-reduction capabilities of a taper — and thereby allow transmission of enough optical energy to match the main part of the prism. The degradation is proportional to the square of the reduction; thus for example it is said that a two-times reducing taper should have NA $\geq$ 0.66, a three-times taper NA $\geq$ 1.05, and a four-times taper NA $\geq$ 1.4, in conjunction with a main-prism NA of 0.35.

This teaching, however, has since been recognized as partly in error. If a high-NA taper is employed to receive the optical image signal from a low-NA main prism (at least if this is done without special precautions), longitudinally diffusing stray light in the prism section can enter the taper. Such diffusing stray light arises, at the fingertip-contacting end face of the prism, from the excitation illumination which is reflected by that end face at steep angles relative to the fiber axes.

If the main prism is short, this adverse effect is aggravated — because the longitudinally diffusing stray light does not have adequate longitudinal diffusion distance in which to escape from the system, before reaching the taper. Since a high-NA taper by defini-

tion has high ducting capability, the stray light even though angled steeply — beyond the ducting range of the main prism — once into the taper is all carried to the sensor.

Such a result is undesirable because the diffusing stray light is uncorrelated with the signal in each fiber, and so badly fogs the image. The stray light can be quite bright, particularly in dark-field cases where it arises from the specularly reflected, unmonitored bright background.

Therefore new measures are needed to accommodate the poor optical signal-to-noise phenomena associated with feeding a high-NA taper from a short, low-NA main prism.

Applications — More generally the art has not heretofore provided an economical optical fingerprint reader module that is amenable to microminiaturization for access control in highly demanding field applications, particularly including common doors and door handles as well as personal weapons — and also encompassing access to use of portable computers and phones.

Time-and-attendance systems, database access systems, public phones, phone credit systems, vehicles, automatic tellers and facility-entry access devices, although not as critical as portable personal equipment or self-contained door-handle systems in terms of size, time, power, identification certainty, etc. would also be meaningfully enhanced by provision of a self-contained microminiaturized reader.

As now seen, the art has not yet provided solutions to important problems; and important aspects of the technology in the field of the invention are amenable to useful refinement.

SUMMARY OF THE DISCLOSURE

The present invention introduces such refinement, and corrects the failings of the prior art. Before offering a relatively rigorous discussion of the present invention, some informal orientation will be provided here.

1. ORIENTATION

It is to be understood that these first comments are not intended as a statement of the invention. They are simply in the nature of insights that will be helpful in recognizing the underlying character of the prior-art problems discussed above (such insights are considered to be a part of the inventive contribution associated with the present invention) — or in comprehending the underlying principles upon which the invention is based.

(a) <u>If a taper is used, it should be a separate element from the prism</u> — Whereas the prism should have low NA to minimize attenuation, and should be free of EMA material, two <u>opposite</u> considerations apply to the taper.

To constrain light within its waveguiding boundaries and minimize crosstalk, and also to match energy flow through the main prism, as mentioned earlier the taper should have <u>high</u> NA and should <u>in</u>clude EMA material. Since the prism and taper thus have diametrically conflicting design requirements for practice of the present invention, they are best fabricated as separate elements.

(b) <u>Focal elements to relay image from prism to sensor</u> — For the present, in view of the adverse economics both of sensors and of tapers, an interim solution is needed. Whereas one ideal would be a low-resolution CCD-like element, meanwhile we prefer to use a focal system — preferably two lenses, or two mirrors.

None of these is fully satisfactory, but such solutions are currently preferred to a sensor or taper. It is contemplated that, for higher volume manufacture of the invention in the future, custom sensors may become available.

(c) <u>Template abstracting for storage, input to or output from self-contained reader</u> — Some utilization means inherently serve a small number of authorized users, for example just one or two. Representative examples include a personal weapon, personal computer or vehicle, etc. For this case a correspondingly small number of templates are to be stored, and it may be best to store them in fully ready-to-use form — with as much preprocessing as possible done in advance to minimize decision-making time.

Where multiple users — for example, a hundred — must be accommodated, however, and slight added decisional delay can be tolerated, it is preferable to minimize storage or data-transmission costs by placing templates in abstracted form such as binary or trinary form (one- or two-bit data). In such situations it is desirable to prefilter, smooth and normalize the data before such preparation for storage or transmission — to be certain that the level-downsampling process does not settle upon nonrepresentative data points.

Similarly after data are recovered from storage, or received by transmission from an external source — assuming that in the actual verification processing the data are used in multilevel form — the data should be <u>re</u>filtered and smoothed, to eliminate spurious abrupt changes (high-spatial-frequency components) in the image.

These considerations apply whether the mode of loading data into the apparatus is to retrieve the data from storage, or read them in from a remote data bank, or read them in from (for example) an identification card carried by the candidate user. In the latter case, the data might be held in a magnetic strip or two-dimensional bar code, or in other ways.

The overall decision as to data formatting for storage (or transmission) depends upon the balance between urgency of decision, as for example in the weaponry case, and cost of storage or data transmission. In a great majority of present applications, transmission and storage are the more-limiting considerations.

(d) <u>Mechanical system for self-contained reader</u> — Representative prior systems occupy housings well in excess of four liters. The present invention, however, combines extraordinarily compact optical, mechanical and electronic subsystems that enable overall reduction to well under two liters.

In the now-preferred embodiment the total system volume, excepting only an external power connection when used, amounts to less than 1400 cubic centimeters. The optomechanical aspects of this achievement call for an optical bench that is unusually compact but without compromise of decisional accuracy — and that is well integrated with the electronics.

In addition the optomechanical system uses a novel fiber-optic prism that is cylindrical, with light-transmitting input and output surfaces essentially at forty-five and ninety degrees to the longi-

tudinal axis of the cylinder (i. e., the so-called "cylindrical axis"). These prisms are fabricated very economically, cut as a series of opposed units from a common optical-fiber cylindrical rod.

(e) Electronic system for self-contained reader — The system uses extremely intensive data processing that is able to make use of essentially all the skin-pattern information that can be collected. This requires a very large, high electrical-power processor, and for most effective use of modern componentry this in turn requires high-power switching-type power supplies.

Such a processor, and such power supplies, radiate electromagnetic interference copiously. Commonly such situations are approached by incorporating physical shielding, massive signal filtering, and placement of components on different boards to isolate them.

In the present invention, however, these components must share a very small housing with an extremely sensitive, high-impedance detector — and with other components which effect data transfer from that detector into the processing circuits at bit-transfer rates of multiple megahertz. Such signal bandwidths are comparable to those of the radiated noise, effectively obviating the option of front-end signal filtering. Furthermore space and weight objectives preclude conventional shielding.

These onerous obstacles have been overcome by an ingenious layout of all the components on a common surface-mount circuit board that minimizes their interaction and enables excellent operation without separate boards, shielding or filtering. The most troublesome component interactions are avoided by placing the components involved — the power supplies and the sensor — at opposite corners of the board.

(f) Doorway access control — Although weaponry applications are exceedingly interesting and of course have a certain glamour, it has been observed that the world contains many more doors than handguns. Therefore in a sense the door market is much more important.

This invention introduces new ways of marrying fingerprint-reading modules with door handles and doorknobs, so that the combination is natural and easy — in other words, ergonomic — to use.

2. MORE-FORMAL DISCUSSION

Now with these preliminary observations in mind this discussion will proceed to a perhaps more-formal summary. The invention has several independent aspects or facets.

(a) A FIRST ASPECT of the invention -- In preferred embodiments of a first of these aspects, the present invention is apparatus for acquiring surface-relief data from a relieved surface such as a finger.

The apparatus includes prism means formed from optical fibers. (A fused bundle of fibers is much preferred to unfused fibers, as the latter — with their high-index-differential boundaries between glass and air — attenuate crosslighting much more rapidly.) The prism means in turn include a first end and a second end.

As will be seen, the phrase "prism means" is primarily used to encompass important embodiments of the invention in which two or more fiber-optic optical elements in series are included in the optical assembly.

The first end comprises terminations of the fibers for contact with the relieved surface. The second end comprises opposite terminations of the same or corresponding fibers.

By "corresponding fibers" here is meant fibers of a second element that may be in series, as mentioned just above. Such a fiber receives light from the fibers in the first element.

A "corresponding fiber" typically is only very roughly aligned with any of the fibers in the first element, so that in practice the light from each fiber in the first element may pass into several fibers of the second -- and each fiber of the second element typically receives light from several fibers of the first. These effects somewhat degrade image resolution, but can be made inconsequential by using prism materials in which the fiber spacing is sufficiently finer than the fingerprint ridge spacing.

The second end of the prism means is for passage of light traveling along the fibers from the first end.

Preferred apparatus according to the first aspect of the invention also includes means for projecting light across the fibers in a region where fiber diameter is substantially constant with respect to longitudinal position — and where numerical aperture is less than one-half — for lighting the first-end terminations. For

breadth and generality in discussing the invention, these means will be called the "light-projecting means" or simply "projecting means".

The basis for the diameter and numerical-aperture conditions is set forth at great length in the Bowker document, incorporated by reference herein, and therefore will not be repeated here. Even though the projected light crosses the fibers and is "for illuminating" their first-end terminations, in some forms of the invention as will be seen it does not necessarily illuminate them directly or immediately upon fiber entry.

A light fraction that is dependent (i. e., whose magnitude is dependent) on contact between the relieved surface and each illuminated first-end termination is ducted from that termination along its fiber. (By "its fiber" is meant the fiber which is terminated by the termination.)

The present invention enables such passage of light, to and from the finger-contacting end of the prism means, to proceed successfully according to the well-known principles of FTIR introduced earlier in this document — despite use of fiber-optic prism means.

In addition the apparatus includes some means for receiving — at the prism-means second end — each light fraction from the first end, and in response forming an electrical signal which is characteristic of the surface relief. Such means accordingly have an electrooptical character; here too for generality and breadth these means will be called simply the "electrooptical means".

The apparatus further includes intermediate focal means for relaying each light fraction at the second end to the electrooptical means. The phrase "focal means" encompasses one or more lenses, one or more mirrors, or combinations of these.

These intermediate focal means form, on the image-receiving area of the electrooptical means, a reduced image of the second end of the prism means. These means include an objective lens for imaging the second end of the prism means onto the electrooptical means, and also some means for flattening the focal surface, and improving uniformity of illumination, at the electrooptical means. The flattening means further include a field lens fixed to or formed in the second end of the prism means.

The foregoing may be a description or definition of the first aspect of the present invention in its broadest or most general terms. Even in such general or broad forms, however, as can now be

seen the invention resolves the previously outlined problems of the prior art. In particular, because the light is injected efficiently from the side but collected economically with a lens system, the invention achieves an optimum tradeoff of performance and cost for the present state of the technology. Use of focal elements enables enjoyment of the crosslit fiber-prism benefits without the cost penalty of a taper or a large CCD.

Although the invention thus provides very significant advances relative to the prior art, nevertheless for greatest enjoyment of the benefits of the invention it is preferably practiced in conjunction with certain other features or characteristics which enhance its benefits. In particular, it is especially desirable that the objective focal length be roughly eight millimeters and the field-lens focal length roughly forty millimeters — and that the objective, prism means and electrooptical means be spaced to provide a reduction factor of roughly three.

(b) A SECOND ASPECT of the invention — Here in its preferred embodiments the invention is self-contained apparatus for skin-pattern verification. The apparatus includes a case having volume less than about two liters (one hundred twenty cubic inches).

Mounted within or for access at the surface of the case are all the following elements;

- means for holding an electrical-energy storage device or for receiving electrical power from an external source, to power the apparatus;

- means for contacting a skin pattern to develop an electronic data array corresponding to an image of the skin pattern;

- means for generating in response a corresponding electronic data array for use in verification;

- means for performing a verification procedure;

- output means for indicating or effectuating, or both, a verification decision;

- means for formatting the data array in a compact form for use in storage, import or export; and

- means for converting the data array from said compact form to a different form for use by the verification-procedure performing means.

(c) <u>A THIRD ASPECT of the invention</u> — In this regard, the invention in its preferred embodiments is self-contained apparatus for skin-pattern verification. The apparatus includes a case having volume less than about two liters. Mounted within or for access at the surface of the case are all the following elements;

- means for holding an electrical-energy storage device or for receiving electrical power from an external source, to power the apparatus;

- means, including an imaging unit and a sensor array disposed to receive an image therefrom, for contacting a skin pattern to develop an electronic data array corresponding to an image of the skin pattern;

- a video controller for controlling the sensor array to develop said electronic data array;

- an analog-to-digital converter for digitizing the data array;

- a digital signal processor for performing verification procedures based upon the electronic data array, and for developing a decision signal based upon the verification procedures;

- memory means for holding an authorized-user skin-pattern template, program firmware for the digital signal processor, and data used in the verification procedures;

- an output register for holding the decision signal;

- output means for transmitting a utilization-means switching signal, based on the decision signal, from the apparatus for effectuation of the decision signal; and

- a control, address, and data bus interconnecting the video controller, analog-to-digital converter, video processor, memory means, and output register.

(d) A FOURTH ASPECT of the invention — The invention in preferred embodiments of its eleventh aspect is self-contained apparatus for skin-pattern verification. The apparatus includes a case having volume less than about two liters.

Mounted within or for access at the surface of the case are all the following elements:

- means for holding an electrical-energy storage device or for receiving electrical power from an external source, to power the apparatus;

- an optical bench disposed or forming part of, or both, the case;

- optical-fiber prism means mounted to the optical-bench bosses for contacting a skin pattern to develop an image thereof;

- an objective lens mounted to the optical-bench ring for relaying the skin-pattern image to a sensor array;

- a sensor array mounted to the optical-bench pocket for receiving said image and in response developing an electronic data array corresponding to the image;

- a surface-mount electronics board holding a digital signal-processing chip for analyzing the data array to verify identity corresponding to such skin pattern; and

- verification-decision indicating or effectuating means, or both.

The optical bench has mounting bosses for optical-fiber prism means. The bench also has a mounting ring for an objective lens, and a mounting pocket for a sensor array.

(e) A FIFTH ASPECT of the invention — In preferred embodiments of this aspect, the invention is an optical-fiber imager for use in a skin-pattern analyzer. The imager includes an optical-fiber prism.

The prism in turn has a cylindrical wall defining a longitudinal axis. It also has fused optical fibers parallel to the longitudinal axis, and a transverse face for output of a skin-pattern image from the prism.

In addition the prism has a generally elliptical, angled face for contacting a skin pattern.

(f) A SIXTH ASPECT of the invention — As to this aspect of the invention, preferred embodiments take the form of a condenser lens for use with an optical-fiber prism in a skin-pattern imager. The condenser includes a convex, generally cylindrical-section surface of a first radius for receiving illumination.

It also includes a concave, generally cylindrical-section surface of a second radius, smaller than the first. This concave surface is for holding the optical-fiber prism and for transferring illumination into the optical-fiber prism.

The phrase "cylindrical-section surface" means a surface that has the form of a section of a cylinder. For example the concave surface preferably is about a half of a cylinder — i. e., a cylinder cut in half longitudinally by a diametral plane parallel to the longitudinal axis of the cylinder.

The convex surface, however, preferably is less than a half cylinder.

(g) A SEVENTH ASPECT of the invention — In preferred embodiments of this aspect, the invention is, in combination, a door handle and lock set for installation in a door. The door handle and lock set, considered together, hold a self-contained skin-pattern-verification apparatus.

The combination includes a lock for mounting in the door, and a handle, interfitted with the lock, for manual operation to open the door. Wholly contained within the lock and handle is apparatus for acquiring surface-relief data from a relieved surface such as a finger.

The apparatus includes prism means formed from optical fibers. The prism means have a skin-pattern contact surface exposed at the

exterior of the lock or handle. The apparatus also includes an electrooptical sensor disposed for receiving an image of a skin pattern through the prism means.

In addition the apparatus includes means for analyzing the skin-pattern image to verify identity based on the skin pattern. The apparatus also includes means, responsive to the analyzing means, for controlling operation of the lock or handle, or both.

All of the foregoing operational principles and advantages of the present invention will be more fully appreciated upon consideration of the following detailed description, with reference to the appended drawings, of which:

BRIEF DESCRIPTION OF THE DRAWINGS

Figs. 1 through 5 are conceptual elevations showing fiber-optic prism configurations with focal-elements relaying an image from the prism to a detector array, for several preferred embodiments of the invention — of which:

Fig. 1 is a bright-field system for use with a thumb or other digit oriented in one direction,

Fig. 2 is a like system for use with a thumb oriented oppositely,

Fig. 3 is a like system with a stepdown-coupling prism that reduces the image in one direction,

Fig. 4 is a bidirectionally illuminated dark-field system, and

Fig. 5 is a dark-field system illuminated with a partial reflector;

Fig. 6 is an electronics block diagram;

Figs. 7 through 11 are elevations in longitudinal section showing fiber-optic prisms built into several door-and-door-handle configurations, of which:

Fig. 7 is a fixed door handle,

Fig. 8 is a rotatable door handle,

Fig. 9 is a like handle configured as a doorknob,

Fig. 10 is a view like Fig. 8 but with an alternative fiber-prism installation, and

Fig. 11 is a like view but with a further alternative fiber-prism installation;

Fig. 12 is an overall system block diagram;

Figs. 13 through 21 relate to optical-prism fabrication, illumination coupling and mounting, of which:

Fig. 13 is a group of complementary orthographic views (end, side, and forty-five-degree-face) of a cylindrical, optical-fiber prism,

Fig. 14 is a rough conceptual side elevation of an optical-fiber rod, taken from a point of view at the side but partly toward one end of the rod, and showing extraction of multiple prisms like Fig. 13 with little waste,

Fig. 15 is an end elevation of the Fig. 13 prism conceptually showing illumination of the prism and an undesired shadowing phenomenon,

Fig. 16 is a ray-trace diagram like Fig. 15 but enlarged and much more precise, and showing operation of a high-quality condenser lens, fitted to the prism,

Fig. 17 is a like view showing operation but for a very inexpensive condenser lens,

Fig. 18 is a forty-five-degree view of the Fig. 13 cylindrical prism, oriented like the upper-right view in Fig. 13 — but enlarged and showing from a different vantage the shadowing phenomenon of Fig. 15,

Fig. 19 is an end elevation (oriented like the left-hand view of Fig. 13) of the Fig. 17 condenser, and;

Fig. 20 is a side elevation (rotated ninety degrees clockwise relative to the central view of Fig. 13) of the same condenser;

Fig. 21 is a top plan of the same condenser;

Fig. 22 is a detailed electronic circuit-board layout showing relative positions of main sections of the circuitry;

Figs. 23 through 31 are electronic schematics, of which:

Fig. 23 is a top-level schematic,

Fig. 24 is a schematic of 3.3-volt and 5-volt power supplies,

Fig. 25 is a schematic of a clock generator,

Fig. 26 is a schematic of a microprocessor and buffer,

Fig. 27 is a schematic of a GLUE PLD,

Fig. 28 is a schematic of data buffers,

Fig. 29 is a schematic of a dynamic memory,

Fig. 30 is a schematic of peripheral data buffers, and

Fig. 31 is a schematic of an EPROM and flash memory; and

Figs. 32 through 34 are mechanical layouts, of which:

Fig. 32 is an isometric sketch taken from above and to left front of the device, with the case drawn in as if transparent to show the relationships of the internal modules with the case;

Fig. 33 is a right elevation of the unit, taken from just inside the right wall of the case, and

Fig. 34 is a left elevation of the optical bench.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

1. OPTICAL CONFIGURATIONS

(a) Bright-field systems — As shown in Fig. 1, preferred forms of the invention include a fiber-optic prism 10 for contact with a relieved surface such as a finger 11 to provide an image of its relieved surface (also designated 11) to electrooptical means 126, 127.

The prism 110 includes a first end 101 for contacting the thumb 11, and second end 120 for transferring the image to the electro-optical means. The prism 110 also includes a side face 103 for receiving light, preferably infrared light, to illuminate the thumb 11; a width dimension of this side face 103 runs in and out of the Fig. 1 plane.

In preferred embodiments as will be seen the illumination-receiving face is a cylindrical wall of the prism — but its operative dimension is substantially independent of longitudinal position. Associated with the prism 110 are a light source 104, and a fiber-optic spacer element or other diffuser 105 to somewhat equalize illumination at the near and far sides of the prism 110. In preferred embodiments, for reasons that will shortly appear, the spacer 105 is replaced by a condenser lens formed as sections of two cylindrical surfaces.

Light rays 114 from the source 104 pass through the optional spacer 105 and cross varying fractions of the prism thickness, as shown, to reach the second end 120 of the prism. In so doing, the light must cross optical fibers 151, preferably fused, which make up the prism 110 and define the prism axis. The light 114 passes into the prism 110 at a steep angle — as understood from Fig. 1 a right angle — to the axis.

Accordingly the light 114 is not ducted along the fibers 151 in reaching the second end 102 of the prism. In particular this light must cross through the side wall of each fiber to reach the termination of that fiber which contacts the second end 102.

Hatching used in the drawings to represent the fibers is only illustrative, since the fibers are essentially microscopic. They are preferably spaced at a small fraction of a millimeter, though not as finely as mentioned in Bowker; the present coarser fibers have been found entirely adequate, and less costly.

The light illuminates the fingertip — and by FTIR relations, as set forth in Bowker, generates an optical image that is ducted along the fibers 151 to the exit 120 of the prism.

From the output face 120, field lens 121 and objective 123 carry the image from the end face 120 to the detector 126, which is in a housing 127. The field lens 121 does not reduce the image, but produces a beam 122 in which precompensation is present for the focal-surface-curving influence to be introduced by the objective 123; i. e., the focal surface as represented in the beam 125 from the objective is substantially flat, to match the flat detector surface 126.

As a matter of ergonomics the Fig. 1 system may not offer the most comfortable or convenient configuration, as no ideal position is left for the rest of a user's hand — knuckles of other fingers, etc. Various ways of dealing with such geometrical considerations are shown in Figs. 9 through 11, but here it may be noted that the thumb may simply be presented from the opposite direction (Fig. 2).

Another minor drawback is that the length of the thumb, applied along the hypotenuse 101 of the prism, appears foreshortened by the factor $\sqrt{2}$ at the output face 120. This anamorphism is very easily compensated in firmware, but at the modest time penalty of an additional processing step.

Anamorphism can be eliminated by fabricating the prism in the form of a parallelogram as shown in Bowker, but with some space penalty. Another approach is to insert a short EMA section 431 (Fig. 3), having the same numerical aperture as the prism, followed by another 45° prism 432 which has a very high numerical aperture NA.

Fibers in the secondary prism 432 are angled at 45° (other angles can be substituted) to the fibers 157 in the main prism, yielding an overall secondary-prism 432 that is narrower by the factor $\sqrt{2}$. This solution corrects anamorphism while reducing the image in one direction so that a smaller factor remains for the focal elements 421, 423.

This configuration has a drawback: coupling between the EMA section 431 and secondary prism 432 may be poor because the interface angles are extreme. Light loss may be severe. To avoid severe fogging of the image in such a device, it is important to use a secondary prism 432, 632 that is properly designed to adequately preserve ducting of the signal rays, particularly through the transition 120 etc. from the primary to the secondary prism.

This constraint calls for a fiber structure 432, 632 of relatively high numerical aperture — but such a structure, without precautions, will also accept stray light across the same interface. The EMA-material buffer 431, 631 is important to avoid carrying stray light from the low-NA primary-prism fibers 151 into the secondary prism 432, 632.

It might be supposed that a series of successively smaller prisms in series could step down the image to the sensor 426 without any focal relaying; however, because each such foreshortening is itself anamorphic it would be necessary to step down separately in each direction (i. e., in the plane of the drawing and perpendicular to that plane). Such a geometry would be rather cumbersome, requiring two cascading prisms for each overall stepdown factor of $\sqrt{2}$, or four such prisms for a factor of two.

Another usefulness, however, of configurations such as that of Fig. 3 is to reduce anamorphically to a CCD 426 that is custom fabricated to a complementarily anamorphic pixel structure. In any of these cases the "prism means" 410, 610 comprise the two prisms 151, 432/632 considered together.

A mechanism for cross-fiber transmission and cylindrical diffusion is not generally recognized, but has been set forth at length

in Bowker. As there explained, illumination undergoes a diffusion-like spread primarily in one plane and angular preservation in the other. To approximate crosslighting penetration, it is possible to use a one-dimensional model that ignores the cylindrical cross-section of the fiber. This approximation yields transmitted flux $\underline{I} = \underline{I}_0 \exp[-\underline{x}\alpha]$, where $\alpha = 2\underline{r}/\underline{D}$ — in which $\underline{x}$ is distance of propagation across the prism, $\underline{r}$ is the loss at each transition from fiber to fiber, the well known expression for reflection due to difference of refractive indices at normal incidence,

$$\underline{r} = (\underline{n}_{core} - \underline{n}_{cladding})^2 / (\underline{n}_{core} + \underline{n}_{cladding})^2,$$

and $\underline{D}$ is the periodicity of the optical-fiber structure in the prism.

A very generally exponential fall-off with propagation depth is expected, leading to an expression for required numerical aperture NA to make any given penetration distance $\underline{x}$ be exactly one attenuation length,

$$\underline{x}\alpha = 1$$

$$NA = 2\underline{n}_{avg}(\underline{D}/2\underline{x})^{1/4}.$$

To obtain this degree of penetration or better, at a distance $\underline{x}_F$ along the illumination path needed to reach the far side of the prism, the condition on numerical aperture becomes instead

$$NA \leq 2\underline{n}_{avg}(\underline{D}/2\underline{x}_F)^{1/4}.$$

Materials offering a moderately continuous selection of numerical apertures, particularly in a low range, are not available now; the most popular materials have numerical apertures NA = 0.66, 0.85, 1.0 and higher. One material commonly on the market does have a low-NA value of 0.35, and this is amply low for the condition described algebraically above. (NA = 0.35 is far too low for good ducting. This leads to a need for caution in variants that require ducting.)

Optical-fiber prism materials with numerical aperture up to about 0.5, were they available commercially now, would correspond to an operationally marginal selection of material; and materials with numerical aperture of 0.36 to 0.42 — or more generally speaking about 0.4 — might be seen as providing an ideal tradeoff between ducting ability and amenability to crosslighting.

Use of a bright-field system has some intuitive appeal, in collecting and analyzing the relatively intense light that internally reflects toward the detector at untouched portions of the

prism face, producing a bright line on the detector corresponding to the locations of grooves in the thumbprint. Such a system produces a fixed upper white level.

Unfortunately in practice the dark level, corresponding to ridges, varies greatly along the ridge lines — from essentially black in some spots to a modulation as high as seventy-five percent (of the white level). The contrast

$$(I_{max} - I_{min}) / (I_{max} + I_{min})$$

commonly ranges from about one-seventh to nearly unity. The undesirably-higher "dark" level in most regions of the ridge lines severely detracts from the overall appeal of bright-field systems.

(b) Dark-field rectangular-prism systems — A suitable prism 210 (Fig. 4) is rectangular and considerably more massive than those of Figs. 1 through 3 (although the length need not be quite as great as shown). Of course the relatively greater mass in itself is a drawback for the most miniaturization-sensitive applications of the invention — particularly personal weapons, portable telephones and the like.

In addition the illustrated auxiliary coupling prisms 205 add considerable undesired size and weight to the assembly. The function of these prisms is to avoid three problems: high reflection losses, low Lambertian (cosine law) flux through each side face 203 of the main prism 210, and difficult source-to-prism alignment.

These adverse effects, however, can be mitigated without adding such large coupling prisms 205. Mitigation is attainable through substitution of a number of smaller prisms, side by side. While it is possible to use a large number of tiny molded facets similar to those of a Fresnel lens, an ideal number is probably small, as for example between two and five prisms.

Tending to offset the drawbacks of greater mass apparent in the main prism 210 of Fig. 45 are higher contrast and improved uniformity of illumination Because lighting can be applied from both sides, some evening-out of the illumination is possible.

With opposed lighting the illumination from each side provides half the intensity at the midplane or centerline 219. In view of the binary character of the FTIR detection process, total midplane intensity (for the $1/\underline{e}^2$ case) is sufficiently close to initial intensity for marginal operation. Beyond that point the intensity

continues to fall off exponentially, so that the intensity fraction which reaches the far side of the prism is the square of the fraction which reaches the midplane.

Light is supplied from twice as many directions — but only half as much light from each direction. Consequently a derivation of numerical-aperture constraints for crosslighting of the Fig. 4 system proceeds to the same algebraic results, except for substitution of the midplane notation $\underline{x}_M$ for the far-side notation $\underline{x}_F$.

The main prism 210 is rectangular not only in the plane of Fig. 4 but also in the width dimension that runs in and out of the plane of the paper. Therefore, unlike the prior-art geometry, the light-entry side faces 203 are at least as wide (not shown) as the thumb-contacting first end 201.

Detector-size concerns mentioned above in connection with bright-field apparatus are even more troublesome here, due to the larger cross-section, by the factor $\sqrt{2}$, of the Fig. 4 rectangular dark-field prism (particularly at its second end 202). They may be addressed by use of focal elements such as lenses 721, 723 (or mirrors).

Unfortunately dimensions of the focal elements or stepdown modules too — and their resulting overall optical-train length — are larger, by at least the factor $\sqrt{2}$, than the analogous bright-field elements 432, 421, 423 and overall optical-train length of the bright-field systems.

Fig. 4 also shows the particularly problematic stray-light rays 214b″ derived from specular reflection 216 of the excitation illumination 214 and diffusely propagating toward the detector — transversely to the fibers, through myriad reflections at the fiber interfaces. These are captured and absorbed by a short section, just before the second end 202, of fibers 251′ that have EMA material.

The short EMA section 251′ can be either a separately manufactured prism block or unitary with the main fiber block 251, as preferred. It is desirable that the numerical aperture of the EMA section 251′ be about the same as the main block 251: if the EMA section 251′ has higher numerical aperture, it will accept and transmit much or all of the stray light -- thus defeating the purpose of the absorbing section 251′. If the numerical aperture of the EMA section 251′ is lower than that of the main block 251, then some signal rays 217 will be undesirably discarded.

As the drawings suggest, the EMA section 431 (Fig. 3), 731 (Fig. 4) need not be long — but again it must not have higher numerical aperture than the main block. Otherwise the following portions of the optical train would fail to serve the purpose of transmitting only the optical signal, and would instead transmit a large fraction of the specularly-derived stray light to the detector.

2. DETECTION

(a) Geometry and mechanical arrangements — As indicated in Bowker, the image produced by the crosslit fiber prism can be detected by using a lens to directly image the output face of the prism onto a self-scanned detector array. The present invention uses such an imaging system.

Many different combinations of element sizes and geometries of course are possible. We have experimented extensively with rectangular blocks cut to 45° prisms as in Figs. 1 through 5. In that format, a representative successful system has input and output prism sides 103, 120 each 16 mm long.

Such a system may be imaged onto a CCD of dimensions 4.8 mm by 6.4 mm (with an 8 mm diagonal) using a field lens 121, cemented directly to the prism and of focal length 40 mm — and an objective 123 of focal length 8 mm. The objective is a compound lens having typically three to six elements.

The object distance (overall length of the beam object segment 122), from prism face 120 to effective central plane 124 of the objective 123, is 34.6 mm. Image distance (overall length of the beam image segment 125), from the latter central plane to the sensitive surface 426 of the CCD, is 10.4 mm. Multiplication (actually reduction) is thus 3.33 and the objective representatively operates at f/1.6.

In such a system the field lens provides no magnification, but serves particularly to provide a flat focal plane at the CCD and also render illumination more uniform there.

We now prefer, however, an innovative cylindrical prism for bright-field systems such as Figs. 1 through 3 — as will be explained in greater detail shortly. For very economical commercial

systems using such a prism, we currently prefer a detector of dimensions 2.4 by 3.4 mm, requiring stronger reduction.

(b) Detector types — Detectors that can be used are primarily CCDs (charge-coupled devices), CIDs (charge-injection devices), and SSDs (self-scanned diodes). All of these are made in two-dimensional arrays by many manufacturers: Texas instruments, Fairchild. Tektronics, Kodak, Dalsa, Phillips, Thomson, Sony, Hitachi and so on — and in a large variety of sizes, and costs.

Smaller and cheaper devices include the Texas Instruments TC211, with 192 by 165 pixels, measuring 13¾ by 16 microns as mentioned above (for overall dimensions 2.64 mm square); and the TC255 with 243 by 336 pixels measuring 10 by 10 microns (overall 2.4 by 3.4 mm, and as mentioned above our current preference). These are made for mass-produced consumer items and cost less than $25.

3. SIGNAL PROCESSING AND ELECTRONICS OVERVIEW

Discussion of the sensor array leads us to the electronic and firmware subsystems of our invention. A very great body of patent and other literature relates to the interpretation and particularly comparison of fingerprint data once acquired. These range from primitive visual analysis to ultramodern holographic correlators with neural- network sensing. Along the way are computerized systems that abstract, classify and compare skin-pattern details called minutiae.

Also known are computerized optical correlators of somewhat greater sophistication, among which may perhaps be categorized the analytical system described in Bowker. Many of these different kinds of data-analysis systems, from visual analysis and minutiae analysis to nonholographic optical correlators including that in Bowker, suffer from inadequate input-image quality — and accordingly would benefit from the teachings of the present invention. Portions of the present invention are compatible with any of the analytical systems just mentioned; in other words, the benefits of the present invention will accrue in use with any of these analytical systems.

One preferred mode of practicing the present invention is in conjunction with a newly developed analytical system and method set forth in the earlier mentioned patent document of Thebaud. His ana-

lytical inventions are of the computerized optical-correlation type, but are extraordinary in many ways: they systematically take into account global or isomorphic dilation or compression of a print due to varying pressure of finger application to the sensor, and differential distortion due to uneven pressure or twisting of the fingertip; in addition they actually use all of the available image data, rather than discarding almost all of it as in all known nonholographic systems.

The firmware resides in a circuit that is in essence a custom computer. It is set into operation by a microswitch 501 (Fig. 6), which in the preferred embodiment is actuated by fingertip pressure on the fiber-optic prism digital signal process 503. In other implementations, a striped vane or other very coarse pattern above the optical input (beyond the finger position) may be used to detect presence of a fingertip to be analyzed; however, this would require maintaining the sensor system in at least partly or periodically operating condition.

Operation of the switch 501 activates a clock generator 502, which clocks a digital signal processor 503. The processor 503 at this point is able to do little more than interrogate a data bus 504 for startup instructions from the "boot" section of a template-and-boot EPROM 507. The EPROM instructs the processor 503 to load its main program and initially needed data from a separate read-only memory 506 into random-access memory within the processor 503.

The processor complies, moving data and program into its internal RAM from the main ROM 506. The signal processor thereby becomes sapient to the extent needed for operation of the entire system through the bus 504.

At that point the system is ready to begin actually processing new data, and the processor 503 via the bus 504 commands a video controller 508 to acquire data. The video control 508 is a custom circuit, or to put it more precisely a custom-programmable logic circuit, which replaces a conventional sensor-reading module known familiarly in the art as a "frame grabber".

A conventional frame grabber would be an entire circuit board, e. g., a card in a personal computer. Hence a massive amount of volumetric compression has been obtained by development of the video control 508 alone, and this is accordingly another important part of the invention.

When thus actuated by the processor 503, the video control 508 takes charge of the front end of the system, commanding a timing generator 509 to start a clock driver — which in turn sequences operation of the sensor array 512. The latter is at present a CCD ("charge-coupled device") as shown, but as mentioned earlier may take any of a number of other forms for greater economy, convenience etc.

As is well known, a CCD is an integrating device. The integration time of the CCD is settable. In the present system integration time is controlled in hardware. For later development stages, however, the processor preferably can be made to monitor contrast in the data array and automatically adjust the integration time so as to optimize the implicit image contrast thereafter — for the particular fingertip, condition of the prism surface, condition of the illuminators, and condition of the CCD.

Analog data from the sensor 512 are buffered 513 and held essentially a frame or major frame subelement at a time in a sample-and-hold circuit 514, from which they are available for conversion to digital form for processing. For convenience of understandable operation, and for convenience of debugging, in the present system — which is at a relatively low-production-volume design stage — the sample-and-hold circuit 514 formats the CCD data as eight-bit bytes in a sixty-four-bit word.

This may be regarded as in essence "real video" in the sense of conforming very generally to conventional broadcast or computer-video-display specifications. For higher-volume design development, however, it is contemplated later to use a custom chip specially programmed for more efficient and faster operation.

While the video control 508 sets these data-acquisition modules into operation, it also synchronizes operation of an A/D converter 517 which reads buffered 515 analog data framewise or wordwise from the sample-and-hold circuit 514 and passes those data in digital form to the processor 503 via the data bus 504. Thus the start-up command launched on the bus 504, from the processor 503 to the video control 508, is answered by a very large flow of data back along the bus from the ADC 517 to the processor 503.

In some applications, additional information such as a personal identification number of other confirming information is required, either before or after the candidate user's fingerprint data are obtained. If so, the processor may ask — audibly, as through a voice

chip 505 and speaker 505', or visually as by means of light-emitting diode indicators through output register 518, or an alphanumeric display 521, or by combinations of these — for entry of such information by the candidate user at a keypad 522.

For this purpose the processor 503 also activates a buffer register 523 to receive inputs from the keypad 522 and return them in an orderly fashion, also along the bus 504, to the processor. As is now commonplace for such processor/user dialogs, the processor advises the user — again by speaker 505', LEDs through output register 518, or display 521 — if for any reason the processor is unable to proceed with the information as entered.

Otherwise the processor uses the information, as for example to select a particular authorized-user template from the EPROM 507, and goes on with the verification work — according to the program instructions and operational data previously read in from the memory 506 — for the fingerprint data received. Upon completion the processor may instruct the sound chip 505, or LEDs, or display 521, or combinations of these indicators, to indicate the decision.

Concurrently the processor, also through the same register 518, may actuate an internal relay 519 to provide a switch closure to an external relay that provides access to utilization means. In more-sophisticated systems as mentioned elsewhere an interactive access actuation can be substituted; and if desired this may be effectuated through the serial communication controller 524 and a conventional RS232 serial-data port 525.

In some systems data may travel in or out of the system for other reasons. Templates may be fetched from a remote computer, or from an identification card carried by the user and inserted into a local card reader. Decisional signals may travel to a remote computer for logging or monitoring. For any of these purposes, once again the serial controller 524 and port 525 may provide needed links to the cooperating apparatus.

4. DOORWAY ACCESS

A fingerprint analyzer according to our invention is readily associated with locking mechanisms of a door 960 (Fig. 7) and built into an associated door handle 961, 962. Power connections (not illustrated) may link the apparatus with an outside supply or with a supply that is internal — e. g., batteries in the lock.

The power is needed for illuminators 904 as well as for actuating the sensor 927 and verification processing system 997. In addition, in the case of Fig. 7 the fixed door handle 961-962 is only used to pull or push the door and has no part in mechanically operating the bolt 963 or its drive mechanism 999.

That mechanism 999, too, accordingly must be powered — most ordinarily by electricity from the supply as for example in the case of a solenoid drive 999. Since the supply must provide enough power to actuate the bolt 963, most ordinarily this particular embodiment will operate from external power rather than from internal batteries.

Light from the illuminators 904 enters the fiber prism 910, which is also contacted by a thumb 11. A different finger can be used, but this particular type of handle is most easily operated by one hand with the thumb 11 at the outer top corner of the handle and other fingers curled about the inclined lower portion 961.

Operation of the print analyzer and the door itself in this way is particularly natural, easy and instinctive. A switch or other means (not illustrated) are provided for initiating operation of the lights 904, sensor 927 and interpretation module 997.

An image of the thumb 11 is collected by the crosslit fiber prism 910, and projected by a field lens 921 toward the objective 923 — which focuses the image on the much smaller active surface of the sensor 927. The sensor 927 responds by passing a data array to the processing system 997, generally in the fashion described earlier in the preceding electronics-overview section of this document; and if the verification is positive the decisional system 997 operates the mechanism 999 to withdraw the bolt 963 from the door jamb.

Equally ergonomic in use is a system with rotatable door handle 961′, 962′ (Fig. 8) — the shaft portion 962′ of the handle being journaled 964 for rotation relative to the door. Here it is the mechanical rotation of the handle that provides the actual motive force for withdrawal of the bolt 963.

For example as suggested in the drawing the bolt 963 may be toothed along its bottom edge to form a rack. The rack engages a pinion 967 that rotates with the door handle shaft 962′.

In this system the decisional module 997′ may perhaps operate a smaller bolt or pin 965 that is withdrawn only from an associated

block within the door. When shot, the pin 965 simply prevents operation of the door handle shaft 962′.

This mechanism requires much less electrical power and so may possibly be suited for operation from a battery.

One variant of the Fig. 8 rotatable configuration uses a doorknob 962″ (Fig. 9) rather than a door handle. The prism here is off-center and its output image coupled by a optical-path folding mirror 932.

If it is preferred to dispose the finger-contacting surface vertically, rather than at a 45° angle, the prism 1010″ (Fig. 10) in another variant of the Fig. 7 or 8 system may be coupled to the relay optics 1021-1024 by a bent fiber-optic element ("light pipe") 1058.

As to the optics, in still another variant of the Fig. 7 or 8 system, a more ideal solution is to mount the sensor 1127 (Fig. 11) directly on the output face of the fiber-optic prism 1110, optionally with wiring 1111′ to carry the signal to the processor.

5. SYSTEMS

Our invention viewed generally may include — i. e., encompass — not only a print-verification system or print analyzer 96, but also an access-control module 97 which acts as an intermediary with utilization means 99. In other words, for purposes of certain of the appended claims the invention does not end at the case of the analyzer 96 but extends rightward in the drawing to include the access-control unit 97.

Similarly for some purposes, and within the sweep of certain of the appended claims, the invention includes the utilization means 99. This simply means that the utilization means, the access-control unit 97, and the analyzer 96, all considered together, are part of a new and improved combination.

The analyzer 96 includes a sensitive surface 91 for contact by a finger, thumb, toe, or other skin-pattern member 11. The sensitive surface 91 is part of a sensor module 92, with lights and detector powered from a supply 95 that either is entirely internal (as

with batteries) or draws power from an external source for conditioning within the analyzer 96.

Signals 11′ from the sensor module 92, representative of the skin-pattern 11 image, are compared with information 21 &c. from a read-only memory 93 (also powered from the supply 95) by a CPU 94. The CPU responds, particularly in case of a favorable decision, with a decisional signal 55e to the access-control intermediary 97.

This signal 55e is preferably not merely a unidirectional on-or-off signal but rather part of an interchange of signals which validates the integrity of the connection as well as the entity whose skin-pattern 11. The access-control module may typically be a switch box or heavier relay that provides a lower-impedance signal, or a specialized drive waveform, or other motive means 98 to the utilization means 99.

The analyzer 96, through the access-control means 97, either enables operation of utilization means 99 if appropriate authorization is embodied in the received image, or maintain the utilization means 99 disabled otherwise. The utilization-means block 99 represents any of a wide variety of applications of a decisional signal 55e or access-control signal 98 such as the present invention generates.

One focus of the present document is upon use of the invention in, or as, a personal weapon; however, the invention is equally applicable to other apparatus, facilities, financial services and information services. The invention is particularly suited to field applications that are extremely demanding in terms of overall micro-miniaturization and low weight, very short decision time with very high certainty and reliability, and low power. Personal weaponry is an application which is particularly sensitive to several of these criteria, but close behind are other portable personal devices such as cellular phones and so-called "notebook" computers.

Use of the invention to control access to public phones, automatic teller machines, and vehicle-usage access — even though much less critical in terms of weight and power — all benefit significantly from the amenability of the present invention to miniaturization without compromise of decision time, certainty, or reliability. In some uses, such as telephonic and in-person credit systems, the apparatus of the present invention does not necessarily actuate a device to automatically grant e. g. credit, but can

instead provide a visible, audible etc. signal to a human operator who then actuates any necessary devices.

Any or all of these means for utilizing access-control signals 98 of the present invention are represented by the utilization means 99.

6. PREFERRED PRISM CONFIGURATION, FABRICATION AND LIGHT COUPLING

A cylindrical prism 530 (Fig. 13) provides several surprising advantages. The prism presents an elliptical face 534, the area of the hypotenuse, which fits the shape of a fingertip. Therefore the prism has no excess material — and fiber-optics prism material is costly.

Furthermore it is fabricated directly from drawn rods 536 (Fig. 14) of fused fiber-optic material. To minimize material loss in fact a large multiplicity of prisms 530a-530d can be cut in a continuing sequence simply by alternating transverse cuts 531 (Fig. 14) with 45°-angled cuts 534.

As illustrated, the resulting successive pieces 530a-d are alternating in their orientation (i. e., successive units of each pair are mutually inverted). Each transverse cut forms a transverse face of two adjacent but opposed prisms, and analogously each angled cut forms an angled face of two adjacent but opposed prisms.

In the preferred embodiment, prism dimensions are 15.5 mm diameter by 16 mm length. One side is cut at 45°. The proprietary "MEGAdraw" process of Incom, Inc. (Southbridge, Massachusetts) is used. Numerical aperture is 0.35, fiber size less than twenty-five microns, with no EMA material.

The cylindrical prism is, however, subject to one awkwardness in illumination. Whereas generally central rays 555 (Fig. 15) pass through the prism along fairly straight paths — as in the rectangular-prism case modeled earlier — rays 551, 552 near the edges or limbs of the structure are strongly refracted at the angled surface of the glass in those regions.

These peripheral rays 551, 552 are therefore redirected inward along sharply inward-turned paths, leaving badly light-starved or shadowed regions 553. The illustration suggests that these regions may be behind the midline of the prism; however, in practice the

exact disposition of these regions depends upon the illumination geometry and refractive indices involved.

To provide more-uniform illumination, we have invented a special cylindrical condenser lens to restraighten the peripheral rays.

A ray-trace diagram for a high-performance condenser 545-547 (Fig. 16) formed from hard glass shows that uniform illumination can be provided in a very short distance. Illumination from the light-emitting diode 541 at far left passes through an integral diode lens 542, and then a concavo-plane lens 543-544.

The beam is tightly collimated in the dimension normal to the plane of the drawing, but in the drawing plane the beam from the concavo-plane lens 543-544 diverges severely to the first cylindrical-section surface 546 of the condenser 545-547. That surface refracts the rays inward, making them almost horizontal within the condenser.

The refractive index of the condenser rather closely matches that of the cladding and/or the average of cladding and cores in the cylindrical fused-fiber-optic prism — which is represented by the half-circle at far right. Moreover the second cylindrical-section surface 547 of the condenser closely matches the external cylindrical surface of the prism.

Due to these matches, the extreme rays 551, 552 undergo only a very little bending at the condenser-prism interface 547. The criterion for judging goodness of illumination here is the horizontalness of the rays in the fiber-optic piece, particularly at top and bottom as already noted. By this measure, the Fig. 16 system performs very well, as can be seen.

Angular spacing of the rays in this outer part is half as great as that of the rays in the center. A tilt in the rays indicates that strong shadowing can be expected near the edge of the prism at its widest part.

A ray-trace diagram for a much less costly alternative condenser 545'-547' (Fig. 17) shows a compromise performance. Actually the axial spacings here are dictated by the optical bench design that set the spacings in Fig. 17; therefore some improvement can be obtained by optimizing for this device rather than accepting the design for that of Fig. 17.

At any rate, the peripheral rays 551', 552' in this case are plainly not controlled as well as the corresponding rays 551, 552 in

Fig. 116. Therefore a certain amount of shadowing 553 (Fig. 18) may be expected, as suggested by the conceptual view of Fig. 15.

In this drawing, illumination is from below, and at an upward angle from right to left. The thin end of the prism is at right. Thus the shadowed regions 553 in this instance are in fact behind the midline as predicted from Fig. 13.

With care this shadowing can be minimized and made essentially insignificant, although performance of the Fig. 16 unit is inherently better. This alternative condenser is made of standard acrylic tubing — costing some forty-three cents per foot — with as-fabricated polished surfaces and is simply cut out of the stock material; it can be made by any machine shop.

In particular, however, care must be taken to avoid separation of the acrylic piece from the fiber-optic piece due to temperature expansion effects that might cause the rupture of a cement (e. g., epoxy) bond. If there is a partial rupture at the ends, where the angles exceed the critical angle the light will reflect at the interface — and in this case the outer third of the prism will not be illuminated, except by diffusion. The preferred embodiment uses relatively coarse fibers, which do not diffuse as much as the finer fibers contemplated previously.

Stresses are smaller for a thinner cross-section at the narrow vertex between the two cylindrical radii. In the present configuration that neck is only 1¼ mm (0.05 inch) thick and so readily bends and stretches to accommodate differential thermal effects — as has been verified by freezer and oven cycling.

The condenser in the preferred embodiment of our invention serves as the mounting piece for the fiber optics and the illumination device as well. Thus it introduces several cost savings.

It is cemented to the prism, preferably with Norland Optical Adhesive type NOA 68. The condenser 545 is formed as a mounting cradle (Figs. 19 through 21) for the prism, with mounting holes 561 and a tapered end as illustrated.

7. LAYOUT

To adequately minimize the effects of electromagnetic interference, the layout of our circuit board (Fig. 22) is critical. Sensitive, extremely high-frequency front-end detector circuitry associ-

ated with the CCDs is at one corner of the board; high-radiation inductive switching power supplies are at an opposite corner.

Video control (timing/frame) are at a third corner, directly opposite the power supplies. The moderately high-radiation digital signal processor (DSP) is intermediate along the edge of the board between the video control and the power supplies.

The mechanical layout (Figs. 32 through 34) of the optics, CCD and I/O devices is also thoroughly integrated functionally with the electronic system. As shown, the unusual optical bench has two legs extending downward, at 45° to the horizontal, from the central body that holds the prism.

The prism is substantially flush with the top of the case, and essentially spring-suspended in that condition (together with the rest of the optical bench) from a case mount (Fig. 34). Downward motion against the springs actuates the microswitch 501 (Fig. 6).

8. ELECTRONICS

Electronic details for all circuits appear in Figs. 23 through 31, which will be self explanatory to those skilled in the art — with the exception of the video control 508 (Fig. 6). That unit, as previously mentioned, is a custom-programmed logic circuit — or programmable logic device (PLD).

The PLD in use is known by its model or designator number C80, and is operated using so-called "glue" logic. Understanding its customized internal operation requires an operational description, which is provided here. The acronyms and other specialized terminology will be clear to those skilled in the art:

C80 MEMORY SYSTEM

Ram Used	*GL44016 256k x 16 EDO, 40nS, 8 chips*
Organization	2 x 256k x 64
Page size	512 DRAM addresses, 4k bytes
Refresh:	512 in 8ms
Transfers:	Little-Endian

MEMORY CONTROL

- /RAS0,/RAS1 – decode 2 banks from C80 /RAS output; only enable when DRAM address select is active. During refresh cycle, both /RAS outputs must be on. Need 5nS PLD to gate /RAS lines. Need to tristate /RAS when /DACK to allow frame grabber to take over.
- /CAS – translated 3.3V to 5V only; no gating needed. Need to tristate /CAS when /DACK is active to allow frame grabber to take over.
- /OE – gated based on /DBEN, DDIR, DRAM address select.
- /REG_OE – DRAM registered outputs. Gated same as /OE.
- Address Lines 12-21 go to DRAMS.

ADDRESS SELECTS

Select Line	Description	Starting Address	Bank size, bytes	AS [2:0]	BS [1:0]	PS [3:0]	CT [2:0]
/EPROM0	Eprom 0, 1 megabyte, 8 bits, 32PLCC; 80nS		10 000	000 (static)	00 (8 bits)	1000 (8)	110 non-pipe, 2 cyc/col
/EPROM1	Eprom 0, 1 megabyte, 8 bits, 32PLCC; 80nS		10 000	010 (256k x n)	00 (8 bits)	1000 (8)	110 non-pipe, 2 cyc/col
/DRAM			100 000 (4meg)		11 (64 bits)	2010 (4K)	100 pipe 1 cyc/col
/STAT_IN	Status In, 8 bits; take 256 locations		100h	000 (static)	01 (16 bits)	1000 (8)	111 non-pipe, 3 cyc/col
/CNTL_OUT	Control Out, 8 bits; take 256 locations		100h	000 (static)	01 (16 bits)	1000 (8)	111 non-pipe, 3 cyc/col
/UART_EN0	Uart, 8 bits; take 256 locations; 120nS		100h	000 (static)	00 (8 bits)	1000 (8)	111 non-pipe, 3 cyc/col
/UART_EN1	Uart, 8 bits; take 256 locations; 120nS		100h	000 (static)	00 (8 bits)	1000 (8)	111 non-pipe, 3 cyc/col

C80 FRAME GRABBER

OPERATION

The frame grabber is implemented in a single PLD that includes a master state machine, an address counter, a DRAM address multiplexer, and a DRAM state machine.

The frame grabber takes over the 'C80 bus and directly puts data into one DRAM byte lane; the other DRAM byte lanes are left untouched. To start a frame grab, the 'C80 writes to a register bit to signal that a frame should be grabbed on the next cycle. the master state machine immediately asserts /HREQ to grab the bus, and waits for /HACK to be asserted. After /HACK has been asserted, the master state machine continues performing /CAS-/RAS refresh cycles to maintain data in the DRAM until /VSYNC is asserted. Upon /VSYNC, the master state machine resets the frame grabber address counter to the starting address and waits for VALID to be asserted. While waiting, the frame grabber DRAM state machine performs /CAS-/RAS refresh cycles to maintain data in the DRAM. Once VALID has been asserted, the CCD data is valid and the state machine takes a new video sample every 160nS. The address counter is incremented after each sample. Data acquisition continues until VALID is deasserted, then /CAS-/RAS refresh cycles are performed to maintain the data. When the next /VSYNC pulse occurs, /HREQ is deasserted and the state machine is stopped.

The frame grabber state machine is synced to the CCD timing generator's 25MHz clock.

One possible cycle by cycle DRAM state machine implementation is to assert /RAS and /WR, then change the address multiplexer, then assert /CAS, then deassert /CAS. This yields a very liberal DRAM cycle with a Tcac of 40nS, a Trac of 80nS and a trp of 40nS.

The VALID signal is generated by the CCD timing generator and indicates when the CCD output is valid.

The frame grabber address counter starting address is dependant on the system memory map which has not been determined yet.

The timing generator may either by the TI CCD timing generator or it may be part of the frame grabber PLD. Other "glue" logic may be incorporated into the frame grabber PLD, depending on PLC device logic and pin resources.

FRAME GRABBER PLD CONTROL LINES:

/RAS0 – RAS for address bank 0. Not asserted during data transfers, but asserted during refresh cycles.

/RAS1 – RAS output for address bank 1. Asserted during data transfers and during refresh cycles.

/CAS0 – /CAS output for byte lane 0. Asserted during data transfers and during refresh cycles.

/CAS1 TO /CAS7. /CAS outputs for byte lanes 1 through 7. Asserted only during refresh cycles.

DRAMAD[0.8] – Multiplexed row and column address outputs to DRAM.

/VSYNC – active low input from video timing generator. Indicates start and end of frame.

VALID – active high input from video timing generator. Indicates valid data from the video A/D.

/VIDEO_CONV – active low output to video A/D. Starts data conversion.

/HREQ – active low output to C80. Requests bus.

/HACQ – active low input from C80. Indicates bus has been given to the frame grabber.

CLK0 – 50MHz clock from C80.

CLK25 – 25MHz clock output to the video timing generator, divided by two from the C80.

/DBEN – high while acquiring data – use resistor pullup on this line.

DDIR – don't care while acquiring data – use resistor pullup on this line.

It will be understood that the foregoing disclosure is intended to be merely exemplary, and not to limit the scope of the invention -- which is to be determined by reference to the appended claims.

WHAT IS CLAIMED IS:

1. Apparatus for acquiring surface-relief data from a relieved surface such as a finger; said apparatus comprising:

prism means formed from optical fibers and including:

a first end, comprising terminations of the fibers for contact with such relieved surface, and

a second end, comprising opposite terminations of the same or corresponding fibers, for passage of light traveling along the fibers from the first end;

means for projecting light across the fibers in a region where numerical aperture is less than 0.5 and fiber diameter is substantially constant with respect to longitudinal position, for lighting the first-end terminations;

wherein a light fraction dependent on contact between such relieved surface and each illuminated first-end termination is ducted from that termination along its fiber;

electrooptical means for receiving at the second end each light fraction from the first end, and in response forming an electrical signal characteristic of such surface relief, said electrooptical means having an image-receiving area that is smaller than the second end of the prism means; and

intermediate focal means for relaying each light fraction at said second end to the electrooptical means, said intermediate focal means forming, on the image-receiving area of the electrooptical means, a reduced image of the second end of the prism means and comprising:

an objective lens for imaging the second end of the prism means onto the electrooptical means, and

means for flattening the focal surface, and improving uniformity of illumination, at the electrooptical means; said flattening means further comprising a field lens fixed to or formed in the second end of the prism means.

2. The apparatus of claim 1, wherein:
the objective focal length is roughly eight millimeters; and
the field-lens focal length is roughly forty millimeters.

3. The apparatus of claim 1, wherein:
the objective focal length is roughly eight millimeters; and
the objective, prism means and electrooptical means are spaced to provide a reduction factor of roughly three.

4. Self-contained apparatus for skin-pattern verification, comprising:

a case having volume less than about two liters, and having mounted within or for access at the surface of the case all the following elements;

means for holding an electrical-energy storage device or for receiving electrical power from an external source, to power the apparatus;

means for contacting a skin pattern to develop an electronic data array corresponding to an image of the skin pattern;

means for generating in response a corresponding electronic data array for use in verification;

means for performing a verification procedure;

output means for indicating or effectuating, or both, a verification decision;

means for formatting the data array in a compact form for use in storage, import or export; and

means for converting the data array from said compact form to a different form for use by the verification-procedure performing means.

5. The apparatus of claim 4, wherein:
the case volume is less than about 1.4 liter.

6. The apparatus of claim 4, further comprising:
means for transmitting skin-pattern image data in said compact form to or from the apparatus.

7. The apparatus of claim 4, wherein:
said formatting means comprise means for level-downsampling the data to develop said compact form.

8. The apparatus of claim 7, wherein:

said formatting means comprise means for mapping the data into two- or single-bit data to serve as said compact form.

9. The apparatus of claim 8, wherein:

said converting means comprise means for placing data in at least one format selected from the group consisting of:

multilevel data,

data expressed in terms of sinusoids, and

data expressed in terms of Fourier transforms,

to serve as said data array for use in verification.

10. The apparatus of claim 4, wherein:

said converting means comprise means for developing data in at least one format selected from the group consisting of:

multilevel data,

data expressed in terms of sinusoids, and

data expressed in terms of Fourier transforms,

to serve as said data array for use in verification.

11. The apparatus of claim 4, wherein the fingertip-contacting means comprise:

prism means formed from optical fibers; and

electrooptical means for receiving light through said optical fibers and in response forming an electrical signal characteristic of such contacted fingertip.

12. The apparatus of claim 11, wherein:

the fingertip-contacting means comprise means for cross-lighting the fibers in a region where fiber diameter is substantially constant with respect to longitudinal position.

13. The apparatus of claim 12, further comprising:

intermediate focal means for relaying light from the prism means to the electrooptical means.

14. Self-contained apparatus for skin-pattern verification, comprising:

a case having volume less than about two liters, and having mounted within or for access at the surface of the case all the following elements;

means for holding an electrical-energy storage device or for receiving electrical power from an external source, to power the apparatus;

means, including an imaging unit and a sensor array disposed to receive an image therefrom, for contacting a skin pattern to develop an electronic data array corresponding to an image of the skin pattern;

a video controller for controlling the sensor array to develop said electronic data array;

an analog-to-digital converter for digitizing the electronic data array;

a digital signal processor for performing verification procedures based upon the electronic data array, and for developing a decision signal based upon the verification procedures;

memory means for holding an authorized-user skin-pattern template, program firmware for the digital signal processor, and data used in the verification procedures;

an output register for holding the decision signal;

output means for transmitting a utilization-means switching signal, based on the decision signal, from the apparatus for effectuation of the decision signal; and

a control, address, and data bus interconnecting the video controller, analog-to-digital converter, video processor, memory means, and output register.

15. The apparatus of claim 14, wherein:

the video controller comprises a programmable logic circuit that is custom-programmed for the apparatus.

16. The self-contained skin-pattern-verification apparatus of claim 15, wherein:

the digital signal processor in operation draws more than ten watts of electrical power, and has a characteristic of generating and radiating significant electromagnetic interference within the case;

the holding or receiving means comprise means for converting input voltage to other voltages used in the apparatus, said converting means having the characteristic of generating and radiating extremely significant electromagnetic interference within the case;

the video controller controls the sensor array to read data therefrom at a multiple-megahertz data rate;

whereby noise filtering is necessarily limited, the video controller is sensitive to radiated electromagnetic interference, and the sensor array is extremely sensitive to radiated electromagnetic interference; and

all of said elements are mounted together on a common circuit board that has a generally rectangular shape, and wherein:

the sensor and related circuitry are disposed in one corner of the circuit board,

the video controller and related circuitry are disposed near a second corner of the circuit board,

the converting means are disposed in a third corner of the circuit board, said third corner being diagonally opposite from the first corner, and being generally across the board from the second corner, and

the digital signal processor is disposed between the second and third corners of the board.

17. The apparatus of claim 16, wherein:

the imaging unit is an optical imaging unit; and

the sensor array receives an optical image from the optical imaging unit and in response generates a high-impedance signal at said multiple-megahertz data rate.

18. The apparatus of claim 17, wherein:

the optical imaging unit comprises prism means formed from optical fibers; and

the sensor array comprises electrooptical means for receiving light through said optical fibers and in response forming said high-impedance electrical signal, characteristic of such contacted fingertip.

19. The apparatus of claim 18, wherein the optical imaging unit comprises:

means for crosslighting the fibers in a region where numerical aperture is less than one-half; and

intermediate focal means including two lenses for relaying light from the prism means to the electrooptical means.

20. The self-contained skin-pattern-verification apparatus of claim 14, further comprising:

a keypad; and

a buffer register transmitting signals from the keypad to the bus.

21. The apparatus of claim 14, further comprising:

an alphanumeric display module connected to receive signals from the bus.

22. The apparatus of claim 14, further comprising:

indicator lights or acoustic annunciator means, or both, for indicating system status information such as the decision signal.

23. The apparatus of claim 14, wherein:

the sensor array is an integrating device;

integration time for the sensor array is settable;

the digital signal processor comprises means for automatically monitoring contrast, as represented in the electronic data array, and in response to the monitored contrast automatically adjusting the settable integration time to optimize effective contrast.

24. Self-contained apparatus for skin-pattern verification, comprising:

a case having volume less than about two liters, and having mounted within or for access at the surface of the case all the following elements;

means for holding an electrical-energy storage device or for receiving electrical power from an external source, to power the apparatus;

an optical bench disposed within or forming part of, or both, the case; said bench having:

mounting bosses for optical-fiber prism means,

a mounting ring for an objective lens, and

a mounting pocket for a sensor array;

optical-fiber prism means mounted to the optical-bench bosses for contacting a skin pattern to develop an image thereof;

an objective lens mounted to the optical-bench ring for relaying the skin-pattern image to a sensor array;

a sensor array mounted to the optical-bench pocket for receiving said image and in response developing an electronic data array corresponding to the image;

a surface-mount electronics board holding a digital signal-processing chip for analyzing the data array to verify identity corresponding to such skin pattern; and

verification-decision indicating or effectuating means, or both.

25. The apparatus of claim 24, further comprising:

associated with the optical-fiber prism means, illumination means for crosslighting the fibers in a region where fiber diameter is substantially constant with respect to longitudinal position and numerical aperture is less than one-half; and

intermediate focal means for relaying light from the optical-fiber prism means to the electrooptical means.

26. The apparatus of claim 24:

wherein the optical-fiber prism means are cylindrical; and

further comprising a substantially cylindrical-section cradle fixed to the mounting bosses and supporting the optical-fiber prism means.

27. The apparatus of claim 26, wherein:

the cylindrical-section cradle is a condenser lens for coupling illumination to the optical-fiber prism.

28. The apparatus of claim 27, further comprising:

illumination means also supported from the cylindrical-section cradle and condenser lens.

29. An optical-fiber imager for use in a skin-pattern analyzer and comprising:

an optical-fiber prism having:

a cylindrical wall defining a longitudinal axis;

fused optical fibers parallel to the longitudinal axis;

a transverse face for output of a skin-pattern image from the prism; and

a generally elliptical, angled face for contacting such a skin pattern.

30. The imager of claim 29, wherein:

the generally elliptical face is at a critical angle for frustrated total internal reflection, relative to the longitudinal axis.

31. The imager of claim 29, wherein:
the generally elliptical face is at substantially forty-five degrees to the longitudinal axis.

32. The imager of claim 31, wherein:
the transverse face is at substantially a right angle to the longitudinal axis.

33. The imager of claim 29, wherein:
the transverse face is at substantially a right angle to the longitudinal axis.

34. The imager of claim 29, further comprising:
a cylindrical-section condenser lens, fixed to the cylindrical wall of the prism, for coupling illumination into the prism.

35. The imager of claim 34, further comprising:
illumination means for projecting illumination through the cylindrical-section condenser lens into the prism.

36. The imager of claim 35, wherein:
the prism and the illuminating means are both supported from the cylindrical-section condenser lens.

37. The imager of claim 36, wherein:
the illuminating means comprise at least one light-emitting diode fixed to the cylindrical-section condenser lens.

38. A condenser lens for use with an optical-fiber prism in a skin-pattern imager, and comprising:
a convex generally cylindrical-section surface of a first radius for receiving illumination; and
a concave generally cylindrical-section surface of a second radius, smaller than the first, for holding such optical-fiber prism and for transferring illumination into such optical-fiber prism.

39. The condenser lens of claim 38, wherein:

the convex and concave cylindrical-section surfaces each have respective longitudinal axes that are mutually parallel but spaced apart.

40. The condenser lens of claim 39, wherein:

the concave cylindrical-section surface is substantially a section of a cylinder;

said section being generally half of a full concave cylinder.

41. The condenser lens of claim 40, wherein:

the convex cylindrical-section surface is substantially a section of a cylinder;

said section being generally less than half of a full convex cylinder.

42. The condenser lens of claim 38, wherein:

the concave cylindrical-section surface is for cementing to the optical-fiber prism; and

the two cylindrical-section surfaces are spaced apart by a web that is thin enough to bend slightly without breaking, to accommodate thermal expansion and contraction with respect to such optical-fiber prism, over a full operating temperature range.

43. The condenser lens of claim 42, further comprising:

mounting holes formed in the lens for supporting the lens and the optical-fiber prism.

44. A method for fabricating multiple optical-fiber prisms each having one transverse and one angled face, said method comprising the steps of:

providing a substantially cylindrical rod of fused optical fibers;

making alternating transverse and angled cuts through the rod to form a series of prisms, each transverse cut forming a transverse face of two adjacent prisms, and each angled cut forming an angled face of two adjacent prisms.

45. In combination, a door handle and lock set for installation in a door, and holding a self-contained skin-pattern-verification apparatus; said combination comprising:

a lock for mounting in such door;

a handle, interfitted with the lock, for manual operation to open such door;

wholly contained within the lock and handle, apparatus for acquiring surface-relief data from a relieved surface such as a finger; said apparatus comprising:

prism means formed from optical fibers and having a skin-pattern contact surface exposed at the exterior of the lock or handle, and

an electrooptical sensor disposed for receiving an image of a skin pattern through the prism means;

means for analyzing the skin-pattern image to verify identity based on the skin pattern; and

means, responsive to the analyzing means, for controlling operation of the lock or handle, or both.

46. The combination of claim 45, wherein:

the prism means have numerical aperture less than one-half.

47. The combination of claim 45, wherein:

the prism means are exposed in the door handle at a position for contacting a part of a hand that is disposed to grip the handle for opening of such door;

whereby the hand need not be moved from the skin-pattern-reading position to open such door.

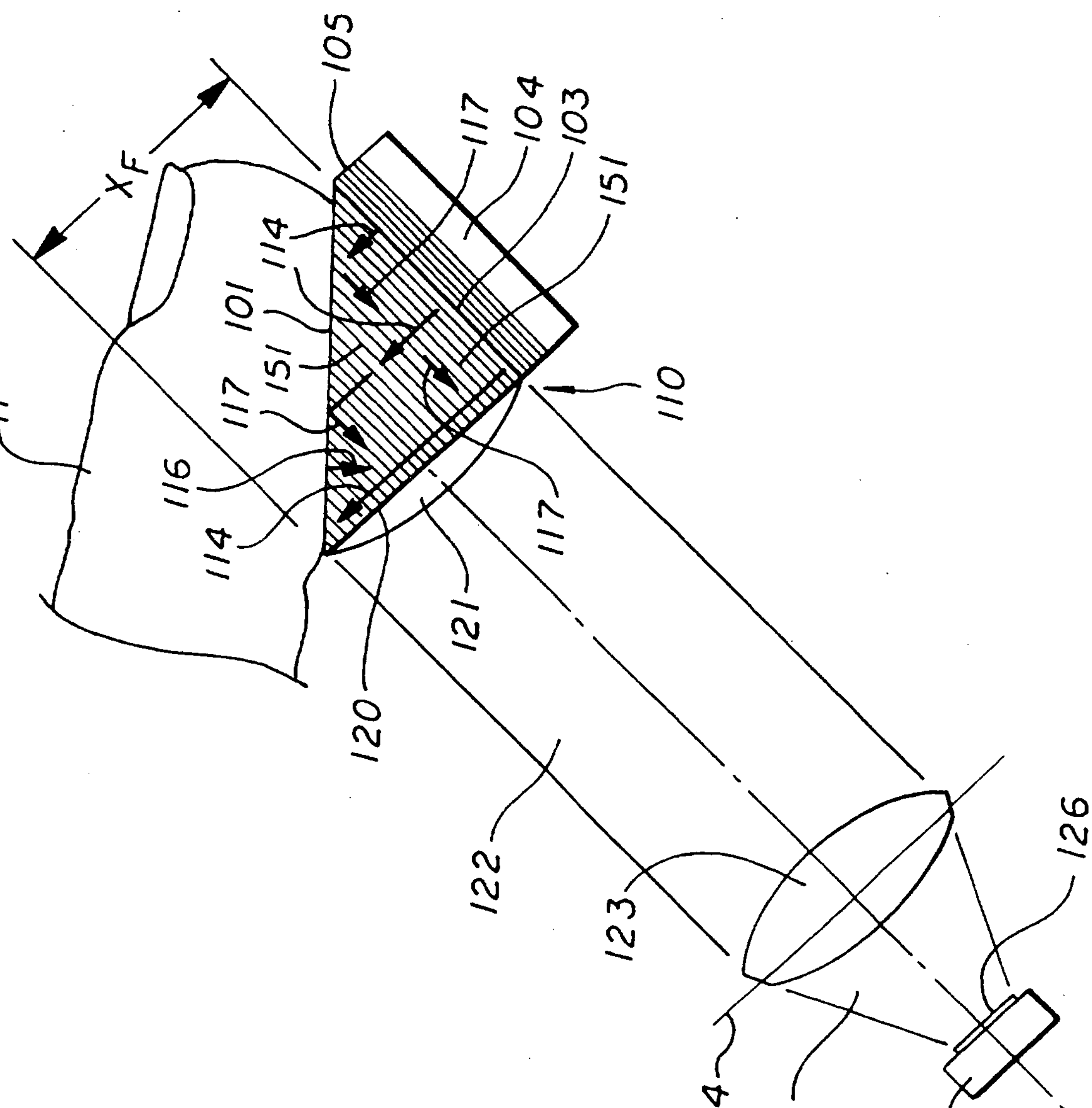
48. The combination of claim 45, wherein:

the prism means are exposed in the handle at a position for contacting a thumb of such hand to acquire a thumbprint therefrom.

49. The combination of claim 45, wherein:

the door handle is a doorknob; and

the prism means are exposed in a protruding end of the doorknob.


105
117
104
103
151
X_F
114
101
151
117
110
11
116
114
117
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122
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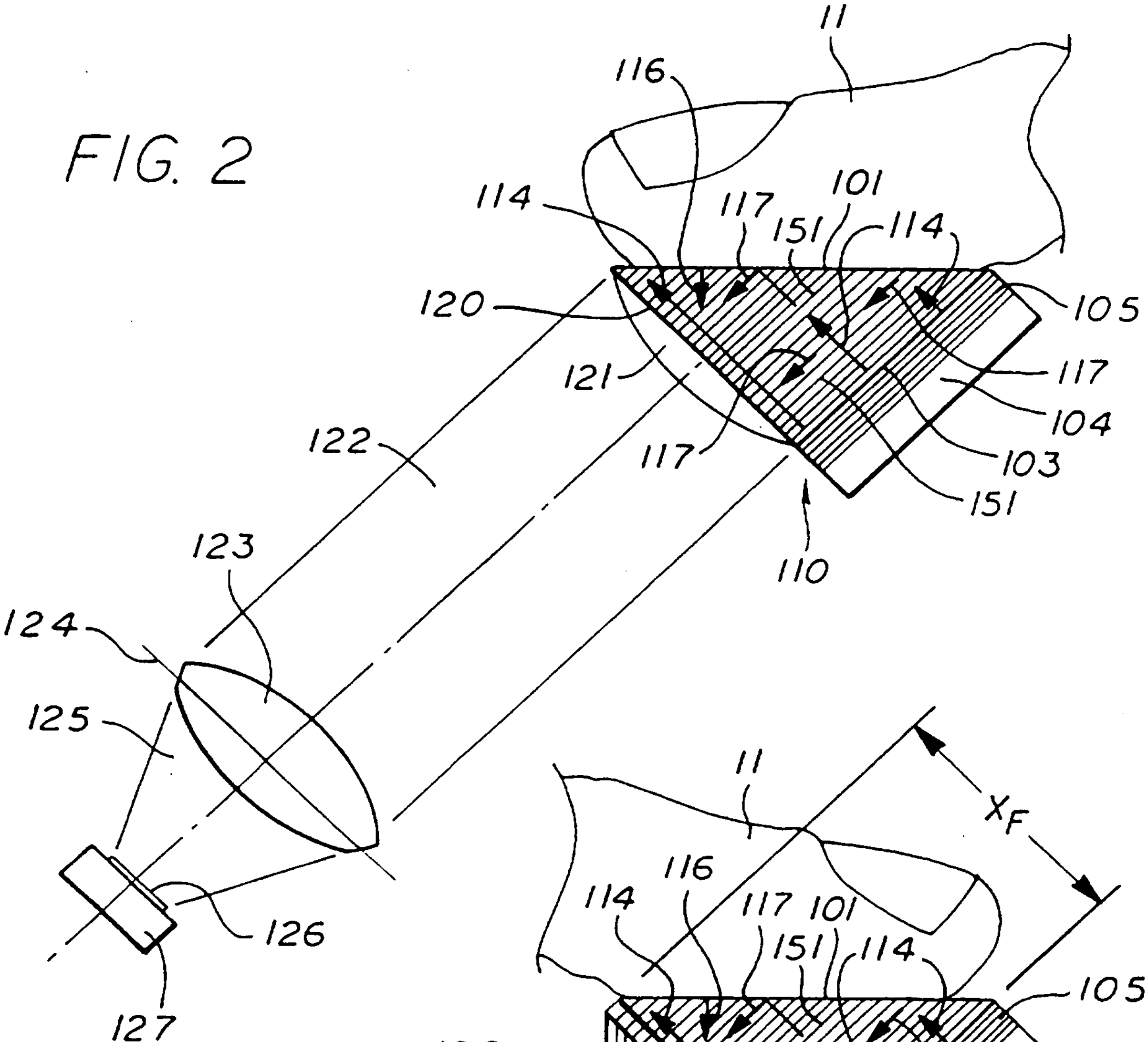
124
125
126
127

FIG. 1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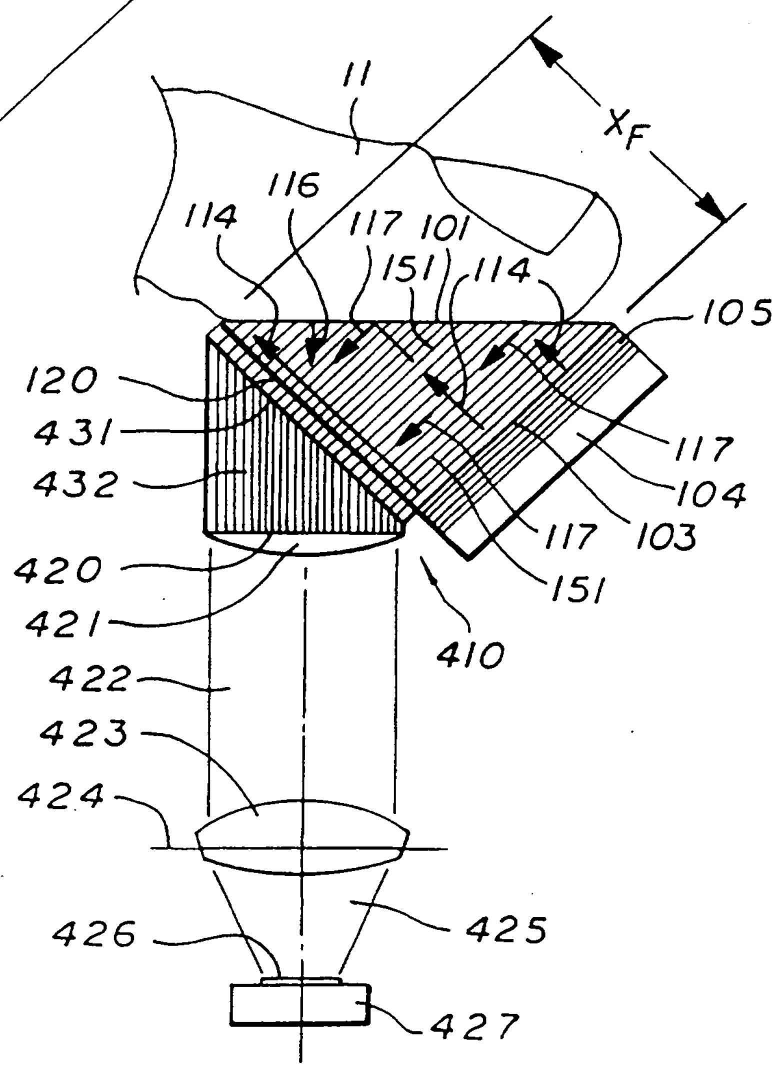
126
127

FIG. 2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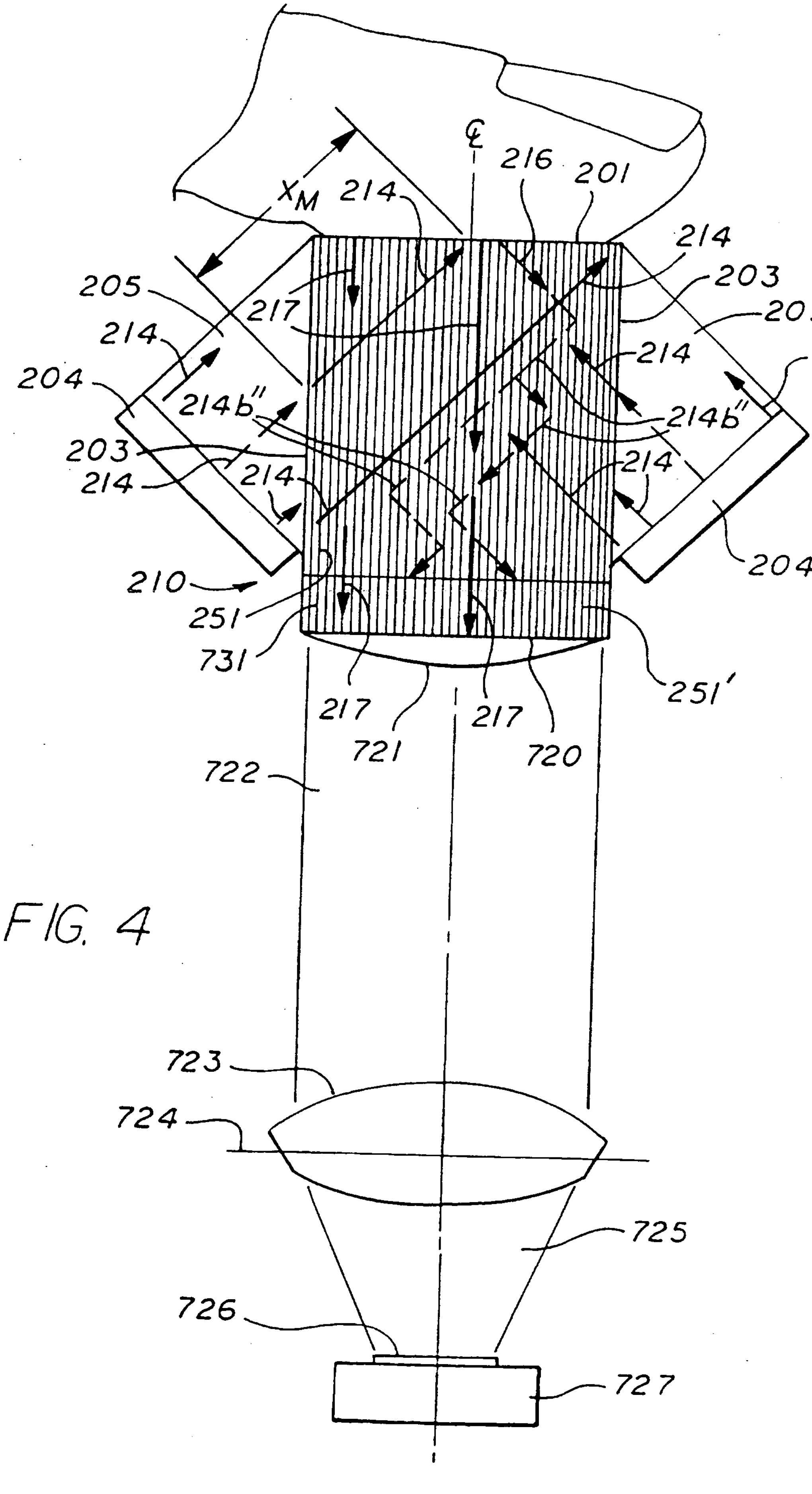
426
427

FIG. 3


℄
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X_M
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214
203
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214b''
203
214
214
214
214
204
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721
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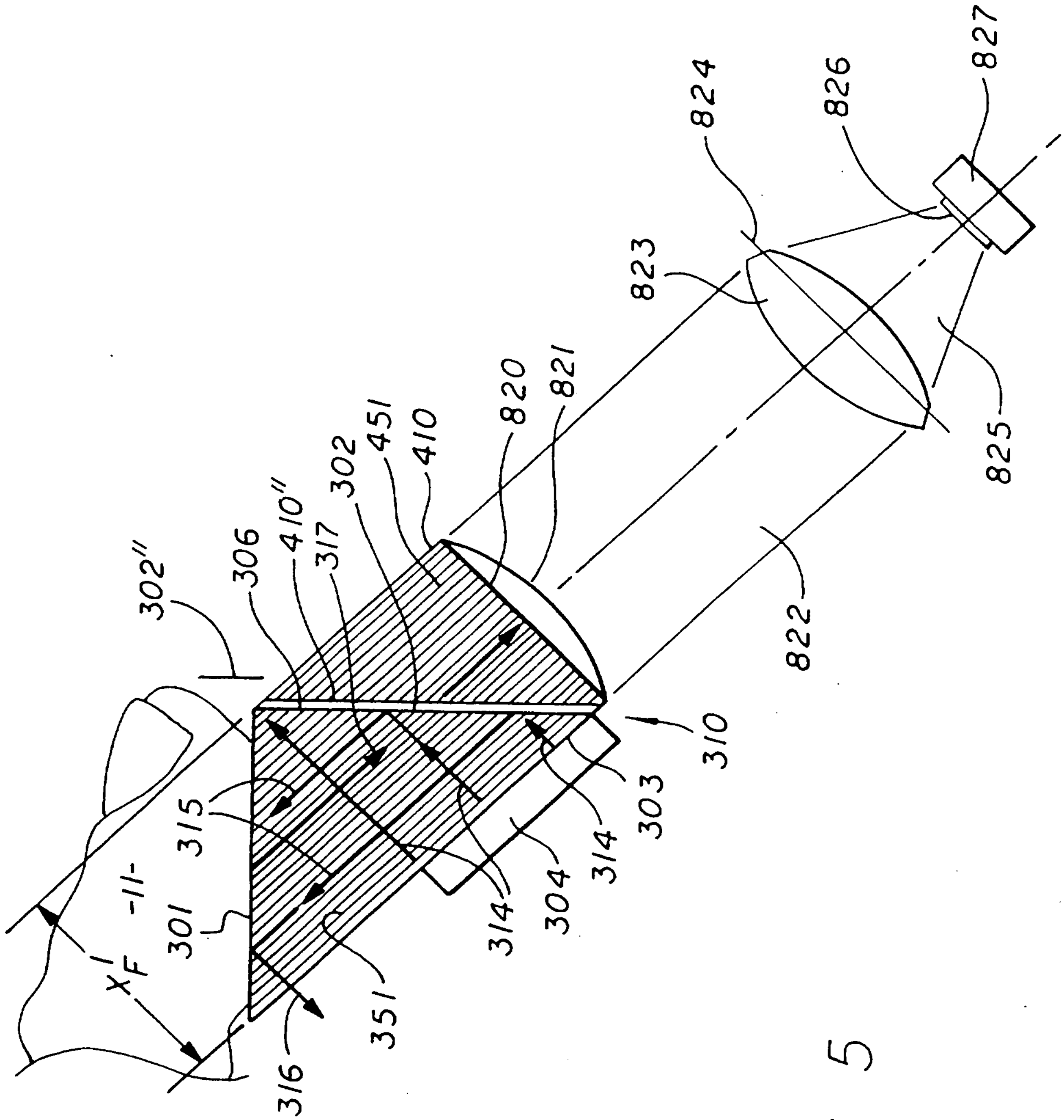
722
723
724
725
726
727

FIG. 4


302''
306
410''
317
302
451
410
820
821
823
824
826
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310
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314
314
304
314
315
301
351
316
-11-
X_F

FIG. 5

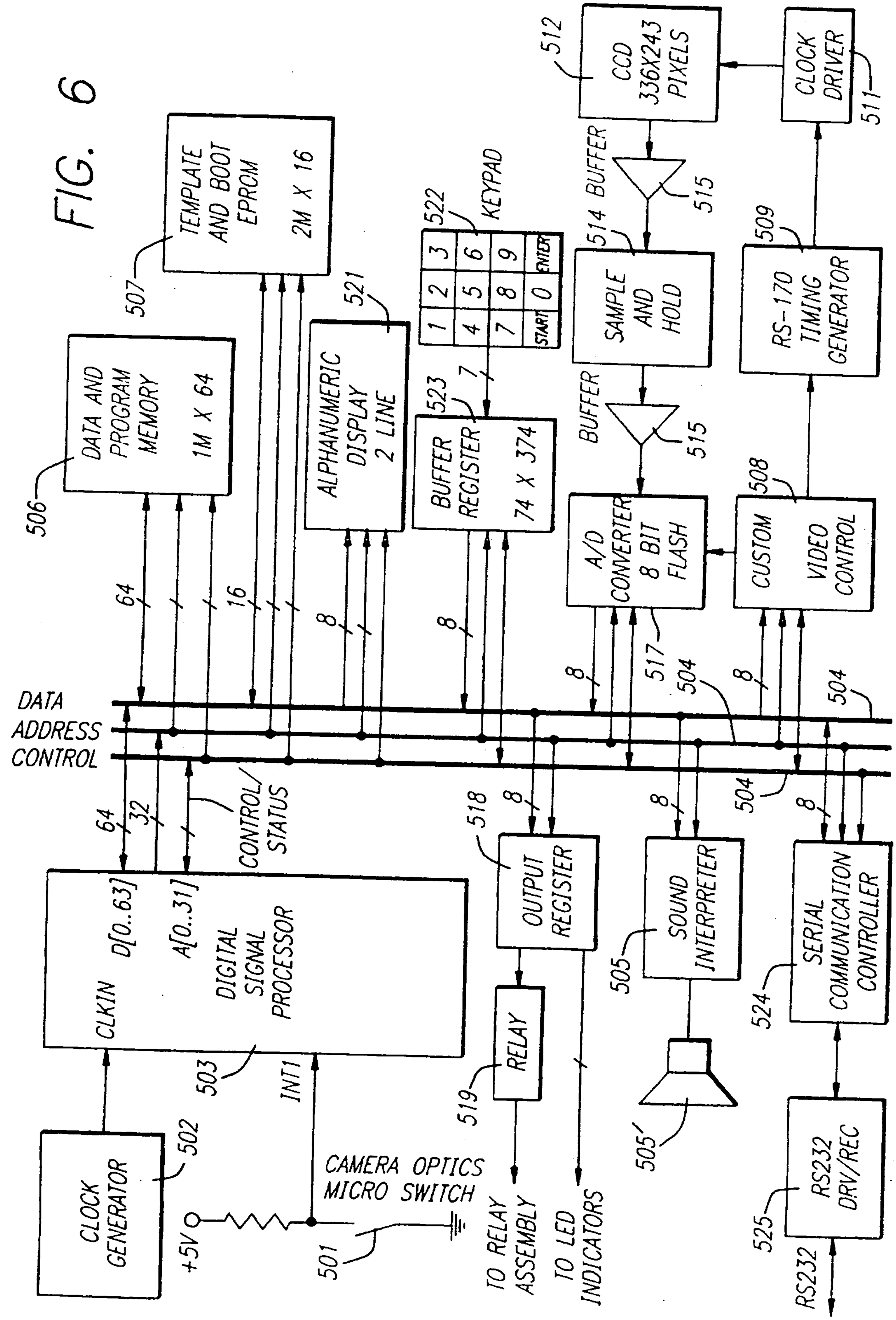
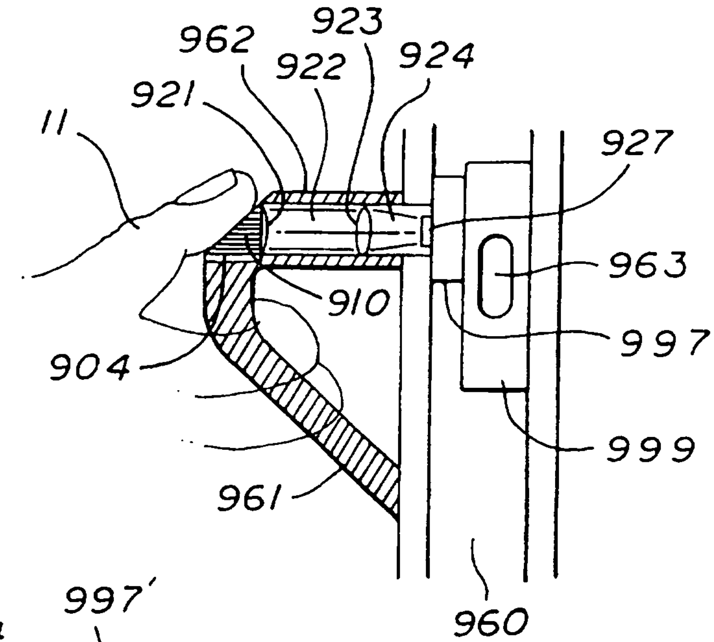

CCD 336X243 PIXELS
512
CLOCK DRIVER
511
514 BUFFER
515
SAMPLE AND HOLD
RS-170 TIMING GENERATOR
509
BUFFER
515
A/D CONVERTER 8 BIT FLASH
CUSTOM VIDEO CONTROL
508
517
TEMPLATE AND BOOT EPROM 2M X 16
507
KEYPAD
522
1 2 3 4 5 6 7 8 9 START 0 ENTER
DATA AND PROGRAM MEMORY 1M X 64
506
ALPHANUMERIC DISPLAY 2 LINE
521
BUFFER REGISTER 74 X 374
523
DATA
ADDRESS
CONTROL
504
64
16
8
32
CONTROL/ STATUS
OUTPUT REGISTER
518
SOUND INTERPRETER
505
SERIAL COMMUNICATION CONTROLLER
524
CLKIN D[0..63] A[0..31]
DIGITAL SIGNAL PROCESSOR
503
INT1
RELAY
519
505'
RS232 DRV/REC
525
RS232
CLOCK GENERATOR
502
+5V
CAMERA OPTICS MICRO SWITCH
501
TO RELAY ASSEMBLY
TO LED INDICATORS

FIG. 6

FIG. 7



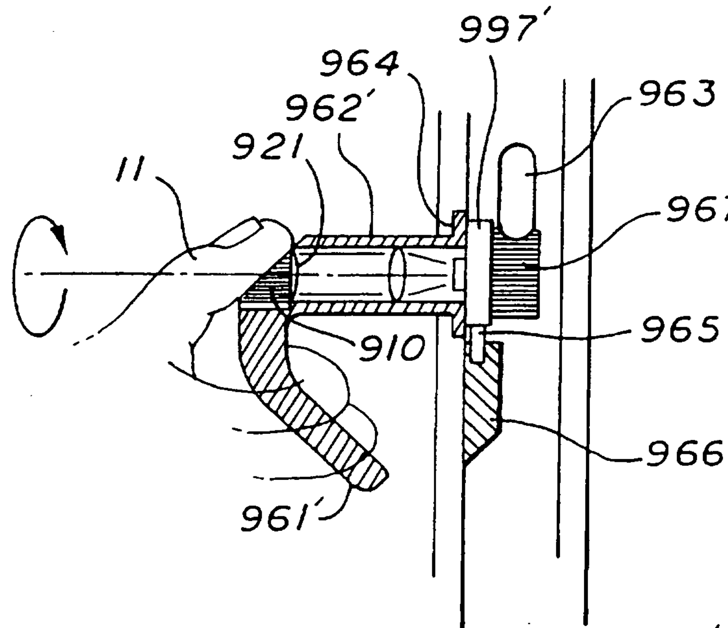


FIG. 8

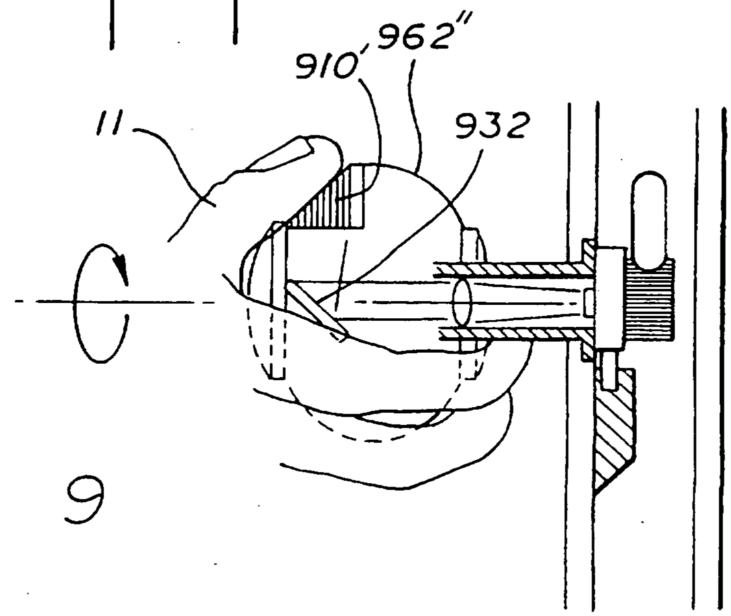


FIG. 9

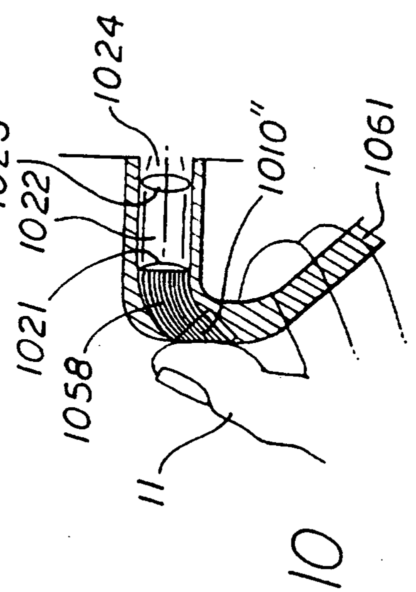


FIG. 10

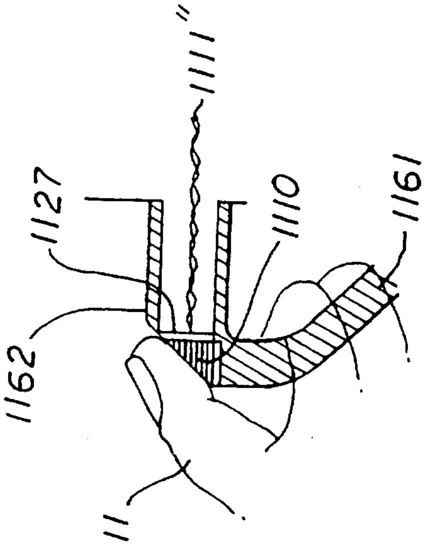


FIG. 11

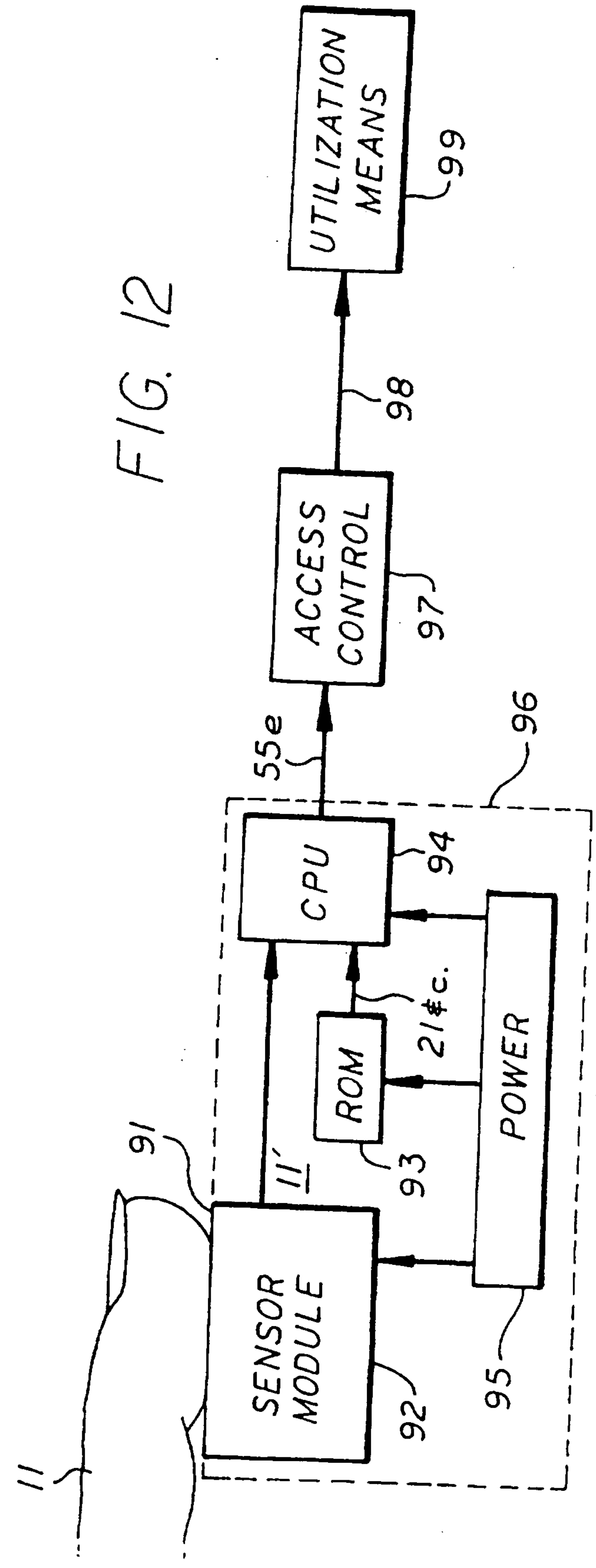


FIG. 12

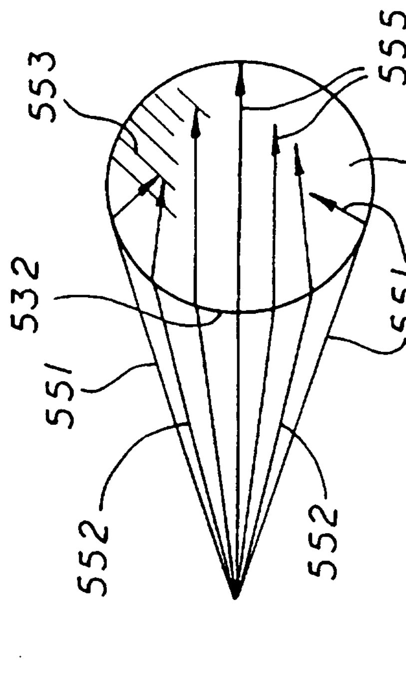


FIG. 15

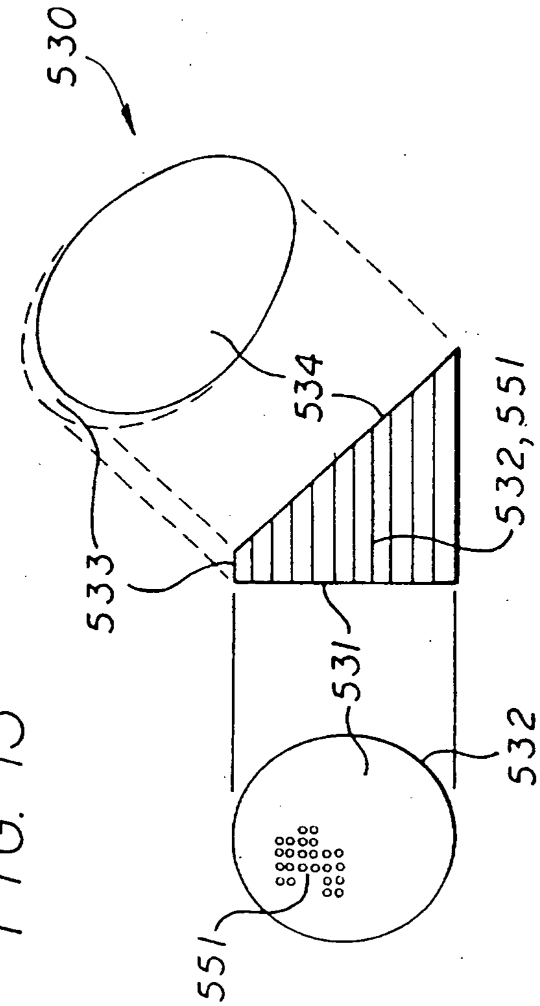


FIG. 13

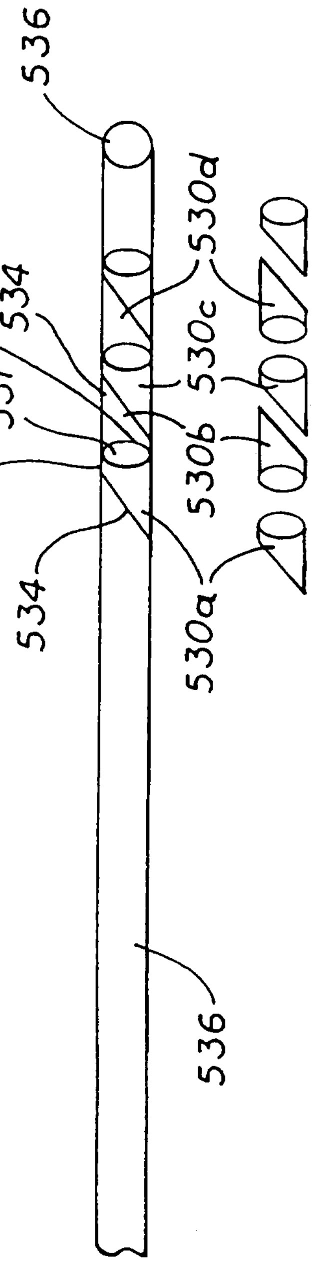


FIG. 14

FIG. 16

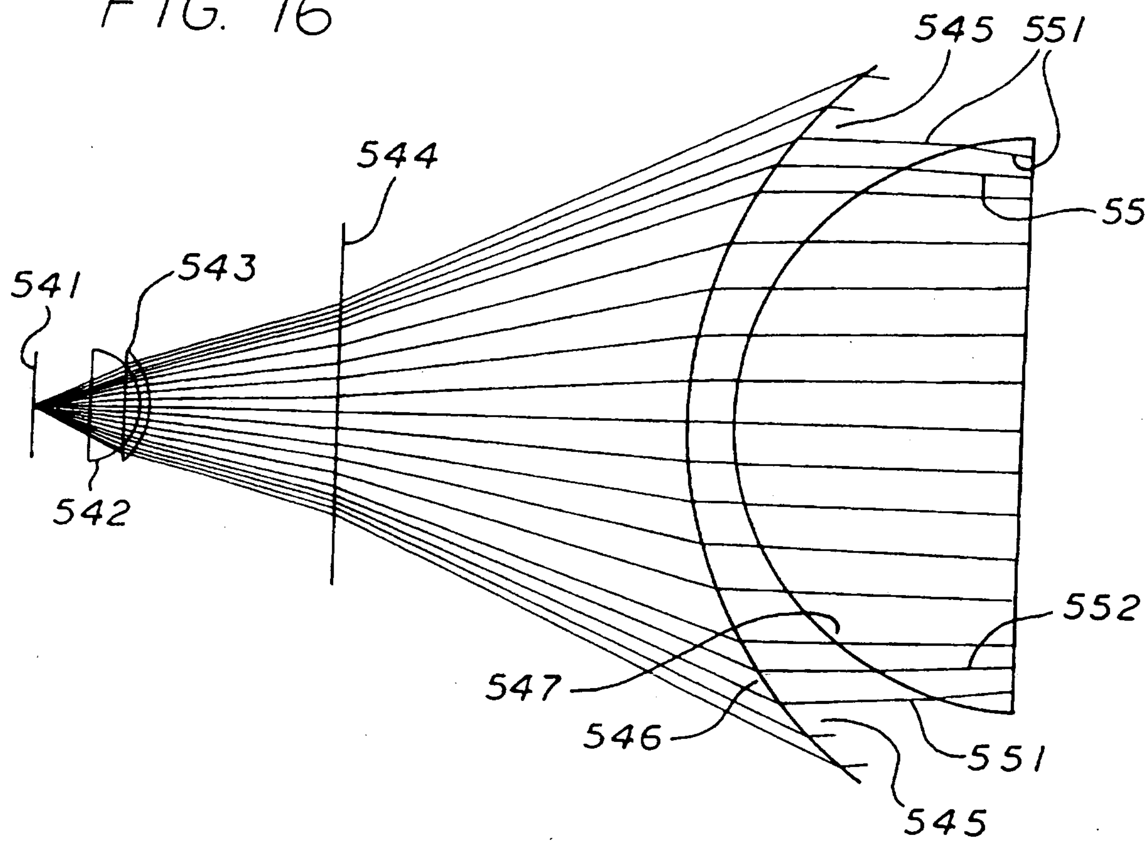
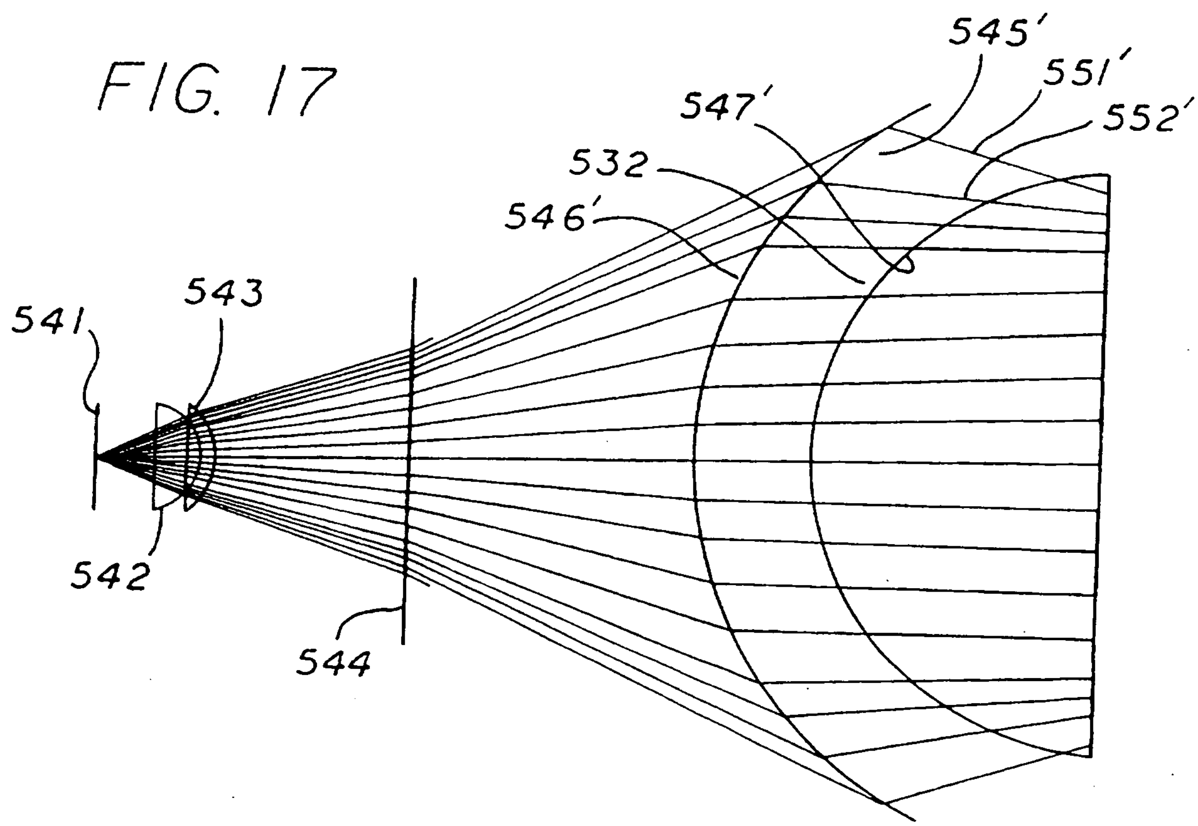

545
551
544
552
541
543
542
552
547
546
551
545

FIG. 17


545'
551'
547'
552'
532
546'
543
541
542
544

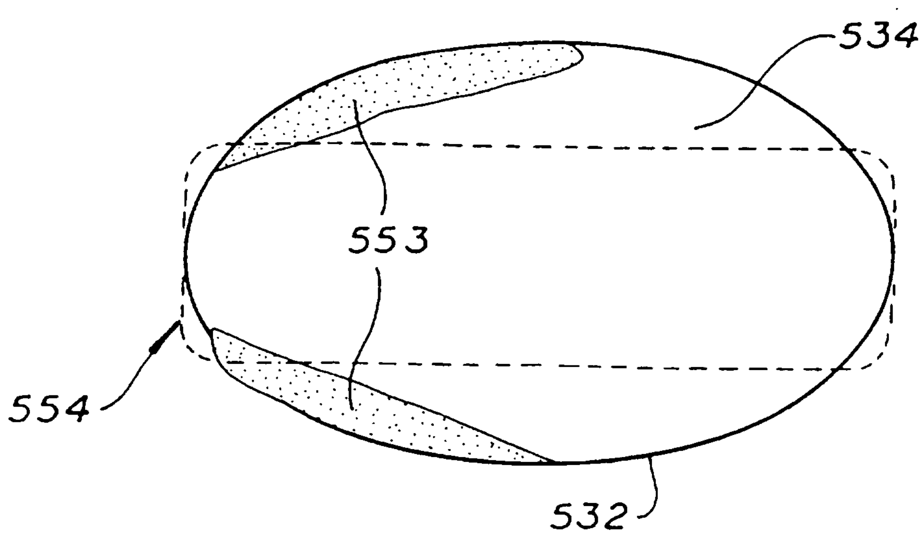


FIG. 18

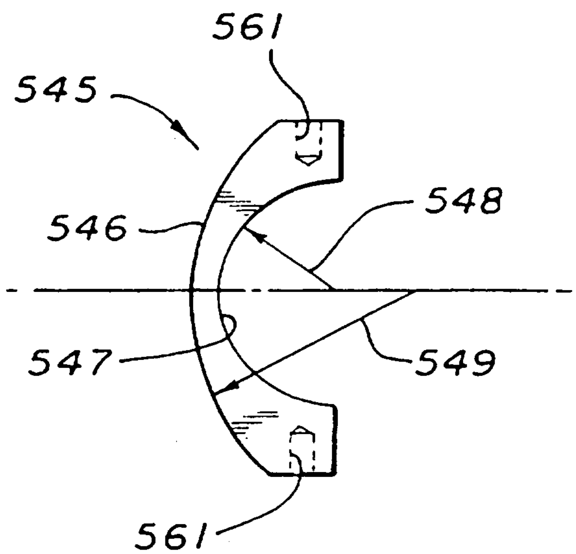


FIG. 19

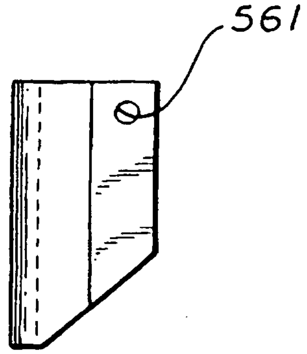


FIG. 20

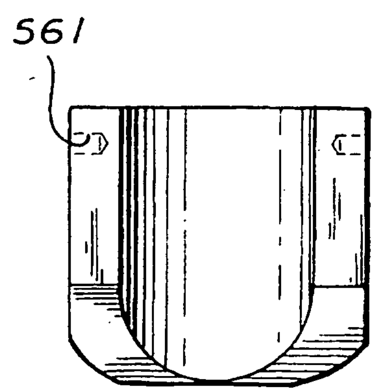


FIG. 21

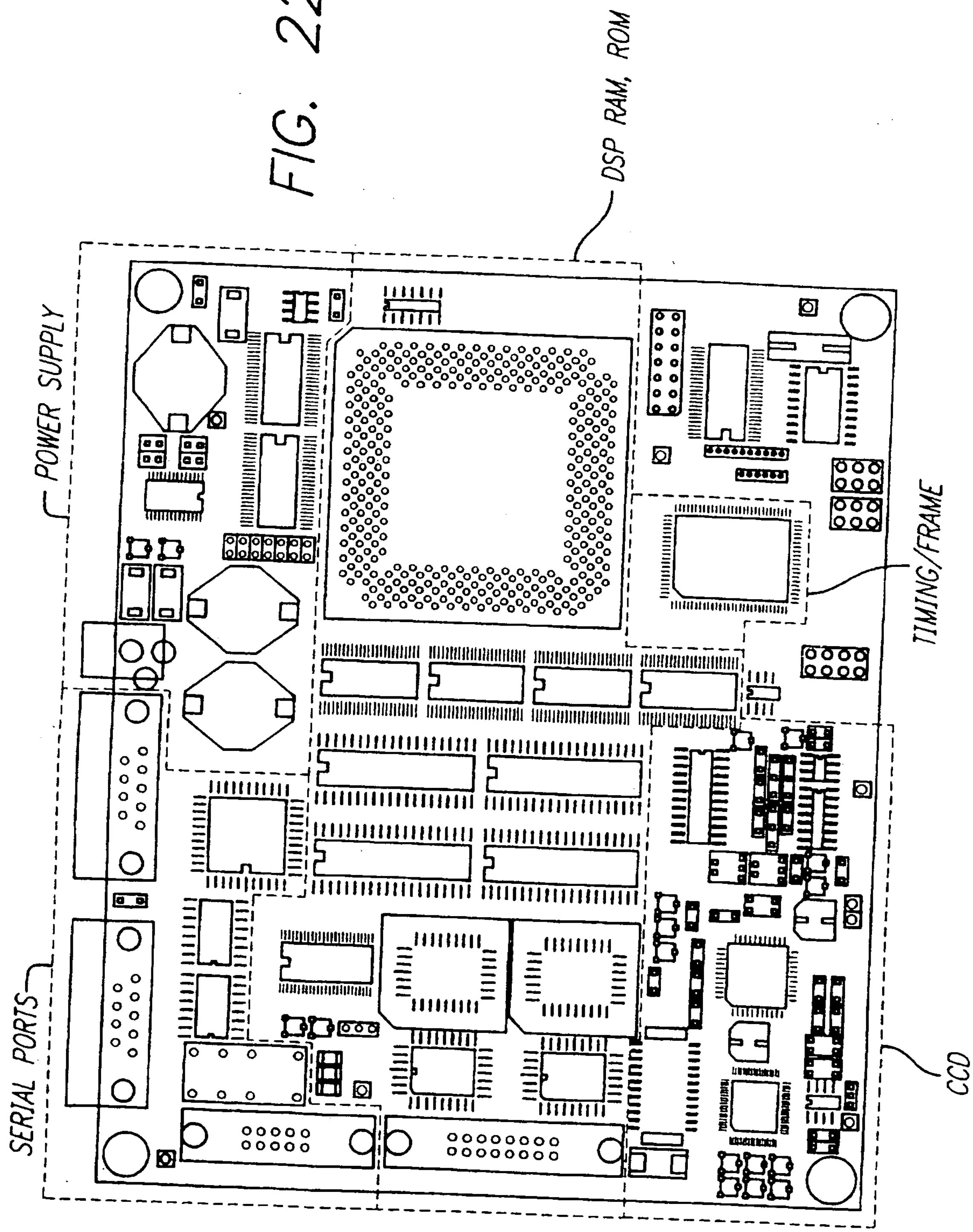


FIG. 22

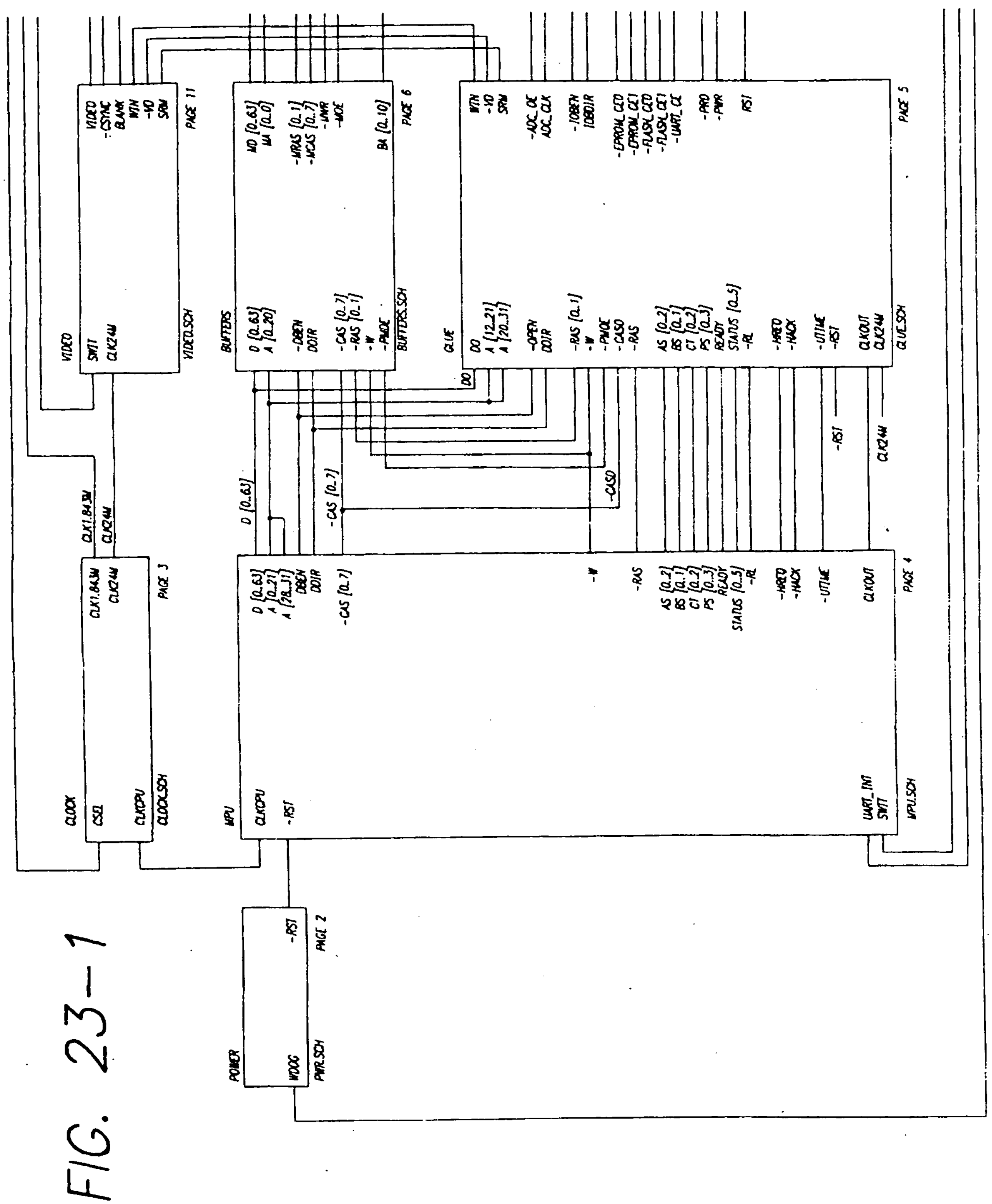

VIDEO
VIDEO.SCH
PAGE 11
BUFFERS
BUFFERS.SCH
PAGE 6
GLUE
GLUE.SCH
PAGE 5
CLOCK
CLOCK.SCH
PAGE 3
MPU
MPU.SCH
PAGE 4
POWER
PWR.SCH
PAGE 2

FIG. 23-1

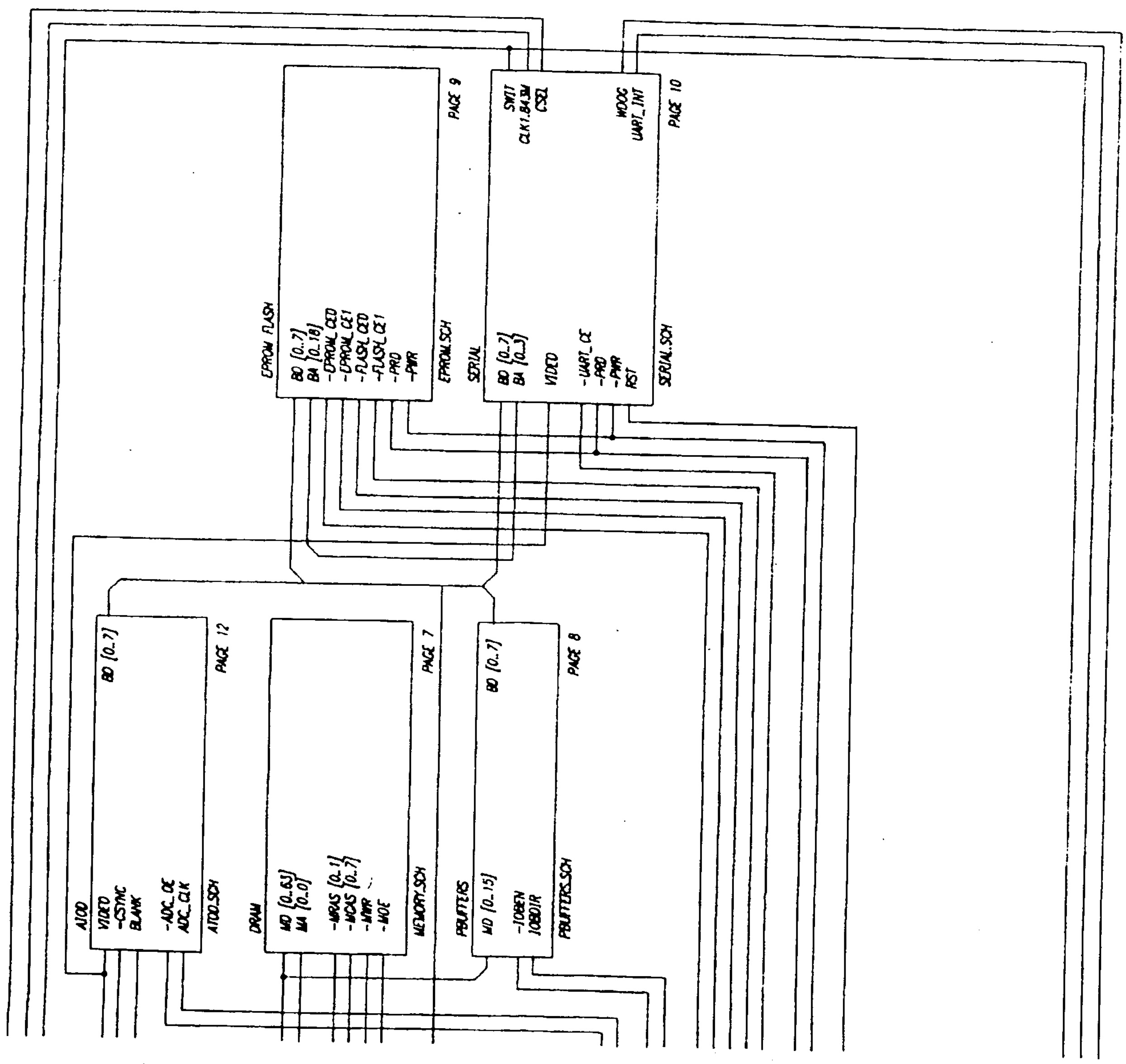

EPROM FLASH
BD [0..7]
BA [0..18]
-EPROM_CE0
-EPROM_CE1
-FLASH_CE0
-FLASH_CE1
-PRD
-PWR
EPROM.SCH
PAGE 9
SERIAL
BD [0..7]
BA [0..3]
VIDEO
-UART_CE
-PRD
-PWR
RST
SERIAL.SCH
SWIT
CLK1.843M
CSEL
WDOG
UART_INT
PAGE 10
ATOD
VIDEO
-CSYNC
BLANK
-ADC_OE
ADC_CLK
ATOD.SCH
BD [0..7]
PAGE 12
DRAM
MD [0..63]
MA [0..0]
-MRAS [0..1]
-MCAS [0..7]
-MWR
-MOE
MEMORY.SCH
PAGE 7
PBUFFERS
MD [0..15]
-IOBEN
IOBDIR
PBUFFERS.SCH
BD [0..7]
PAGE 8

FIG. 23-2

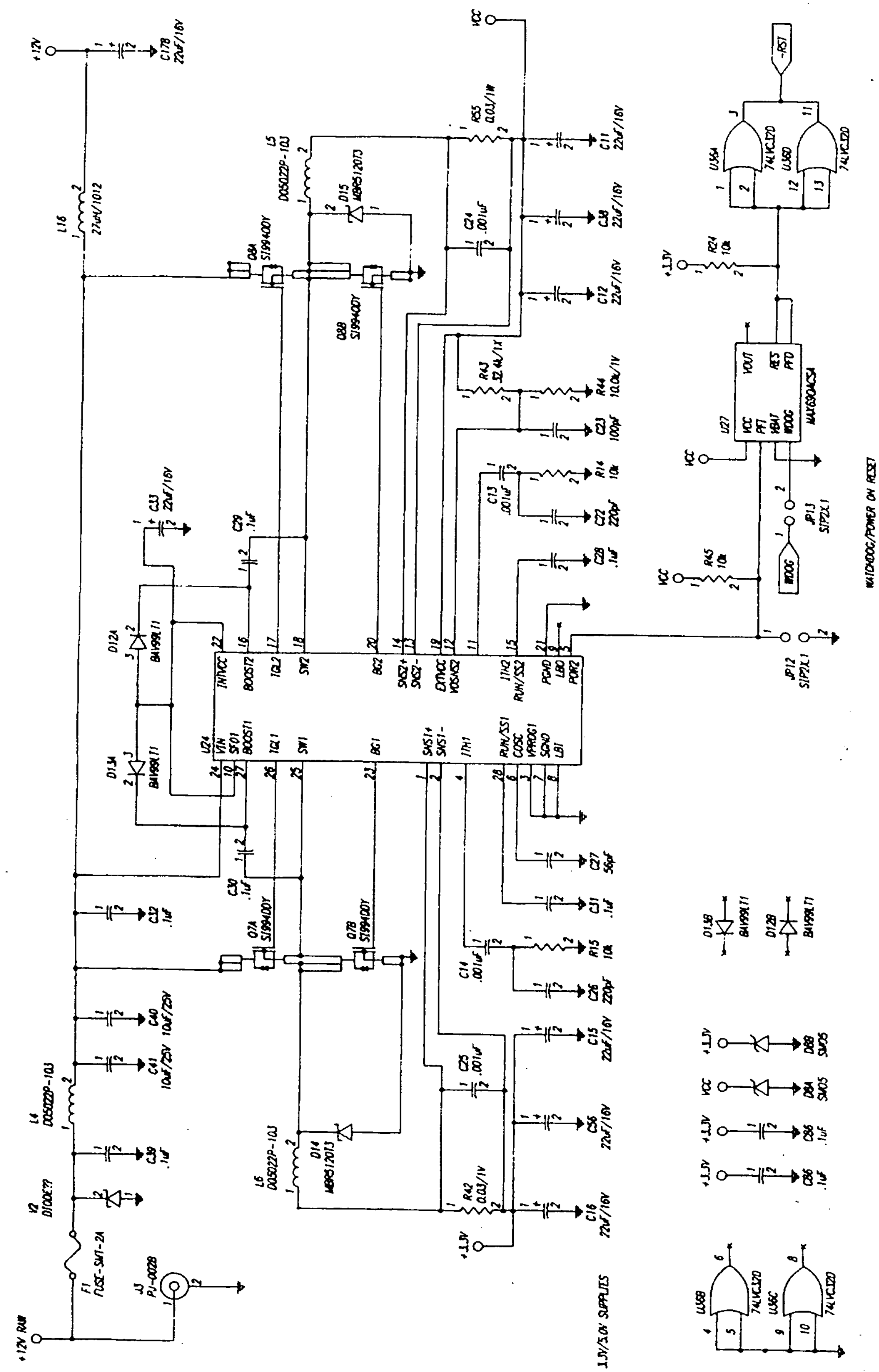
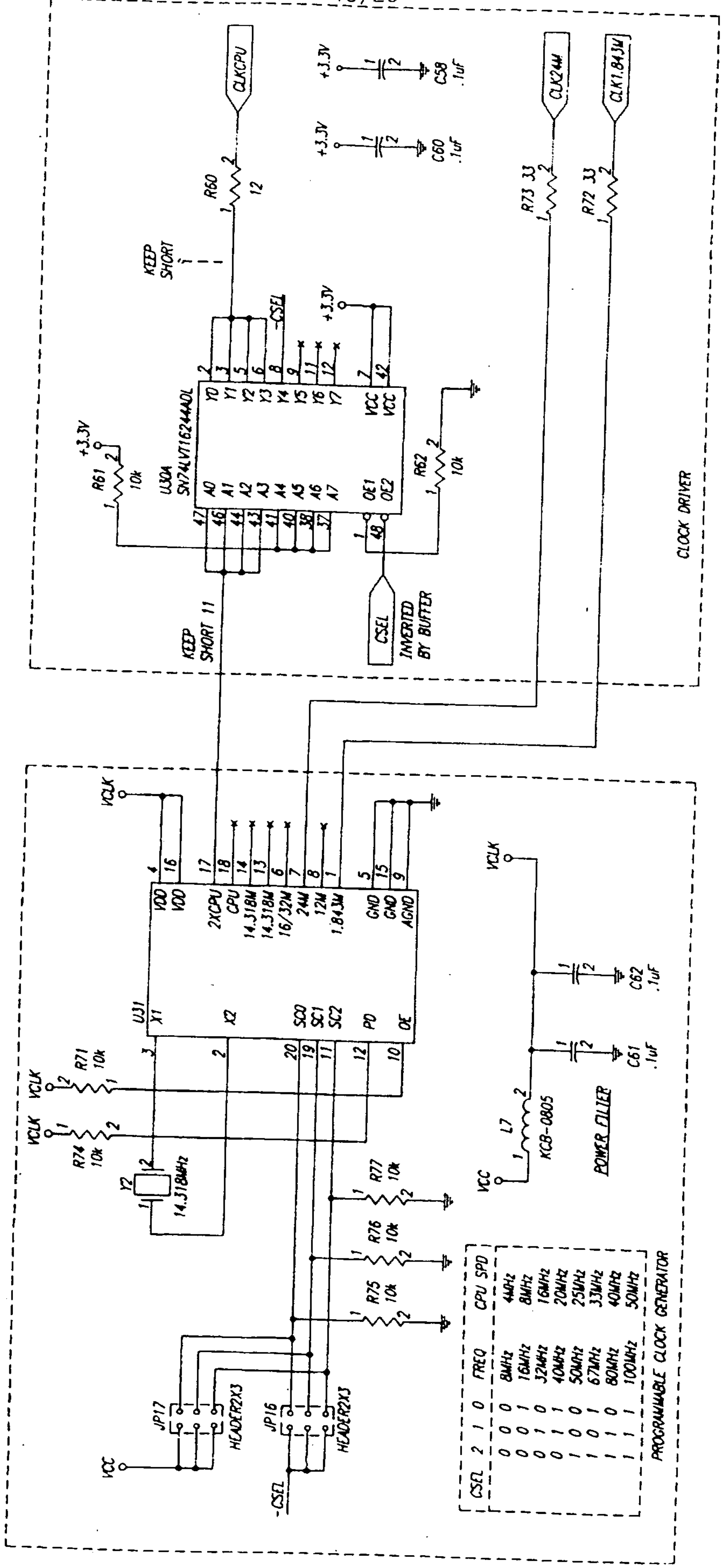


FIG. 24



CSEL 2	1	0	FREQ	CPU SPD
0 0	0	0	8MHz	4MHz
0 0	0	1	16MHz	8MHz
0 0	1	0	32MHz	16MHz
0 0	1	1	40MHz	20MHz
0 1	0	0	50MHz	25MHz
0 1	0	1	67MHz	33MHz
0 1	1	0	80MHz	40MHz
0 1	1	1	100MHz	50MHz

FIG. 25

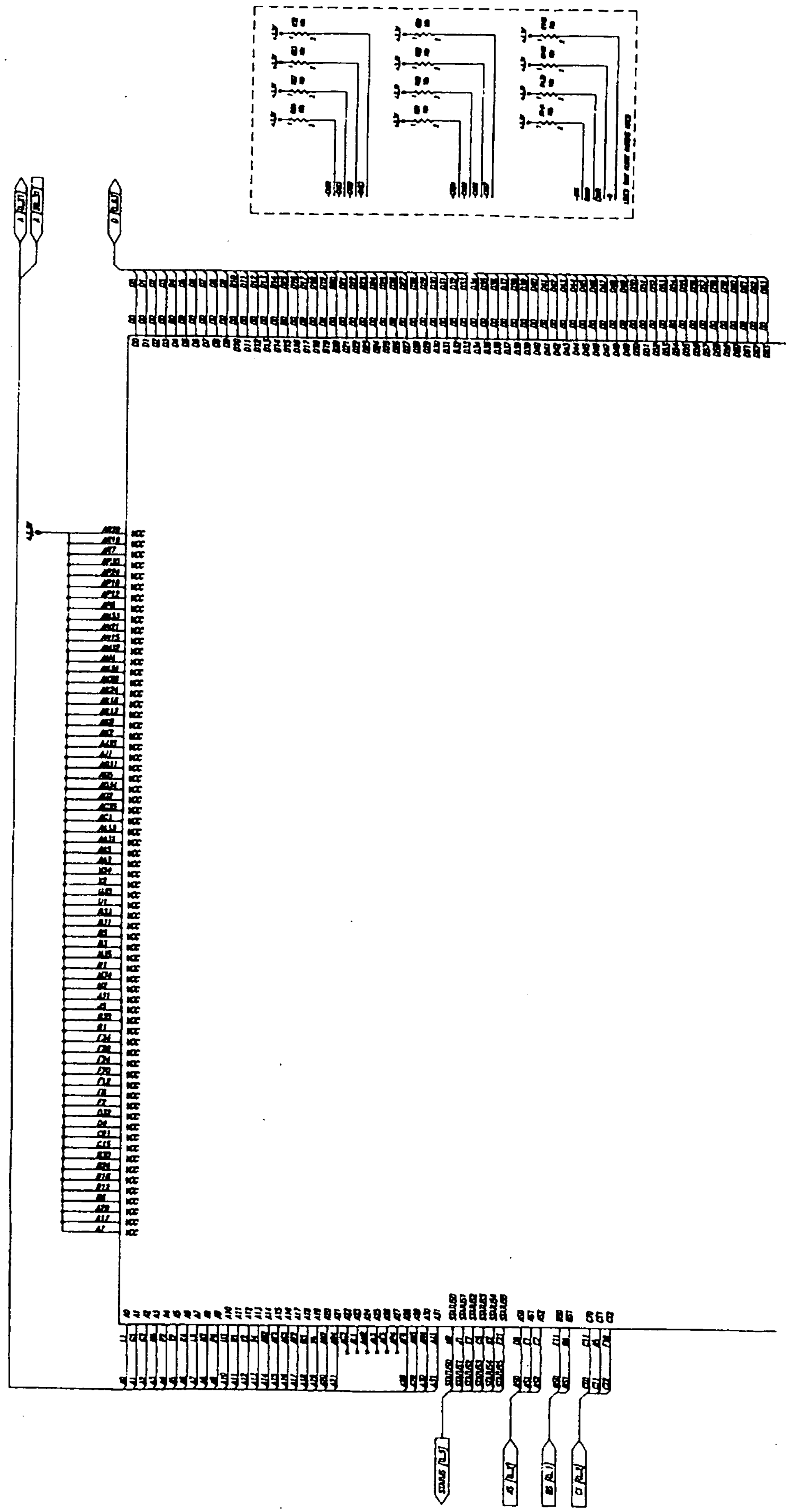


FIG. 26-1

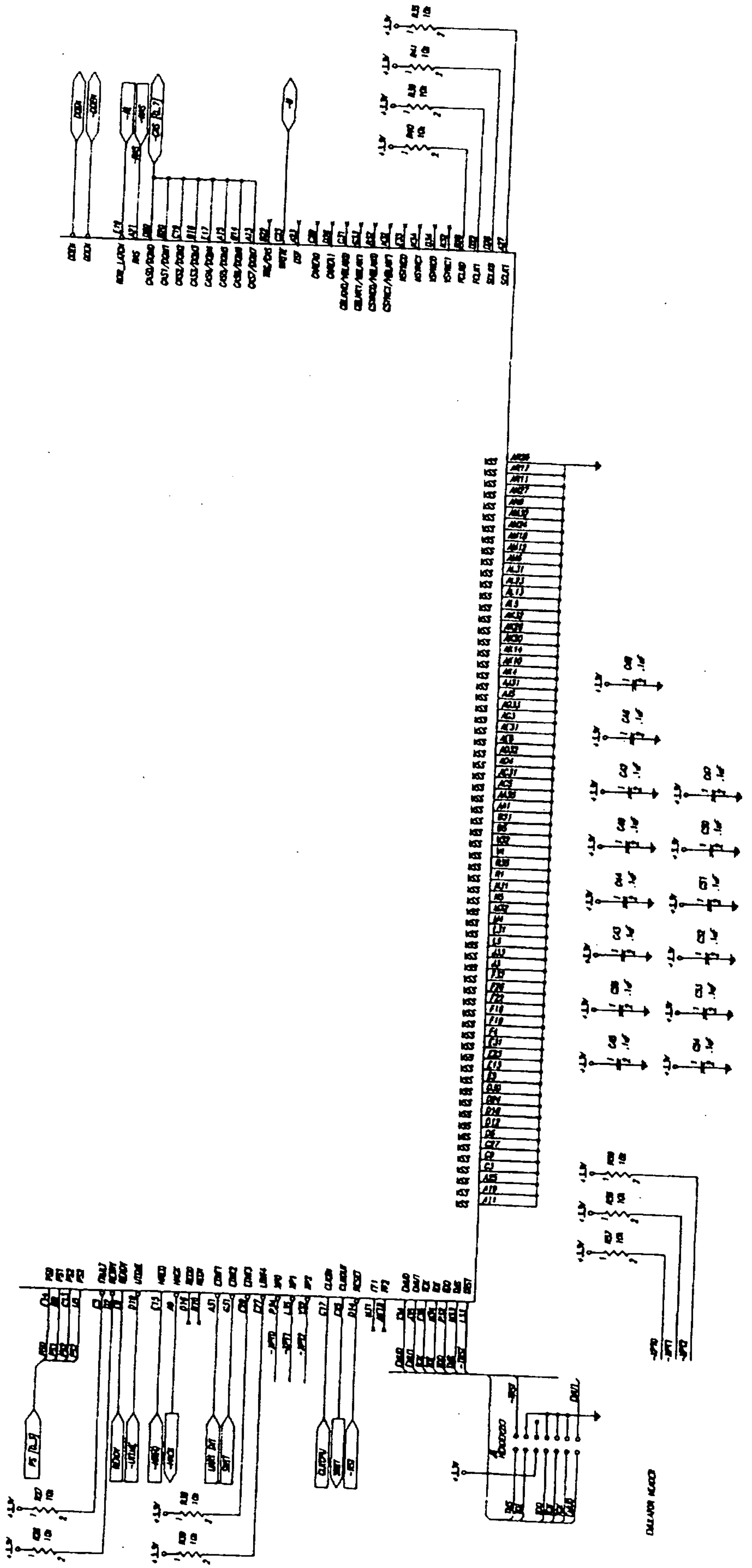


FIG. 26-2

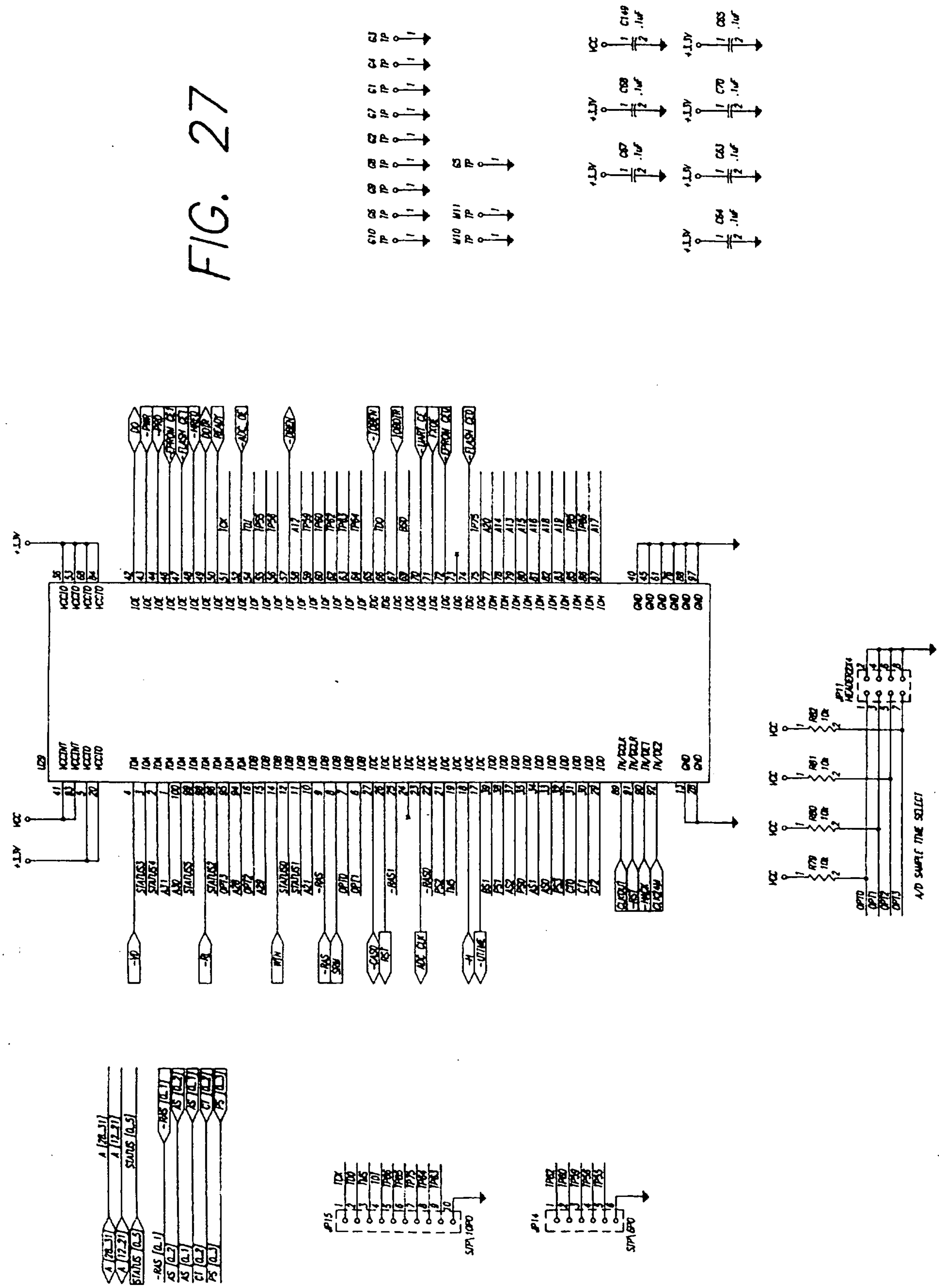


FIG. 27

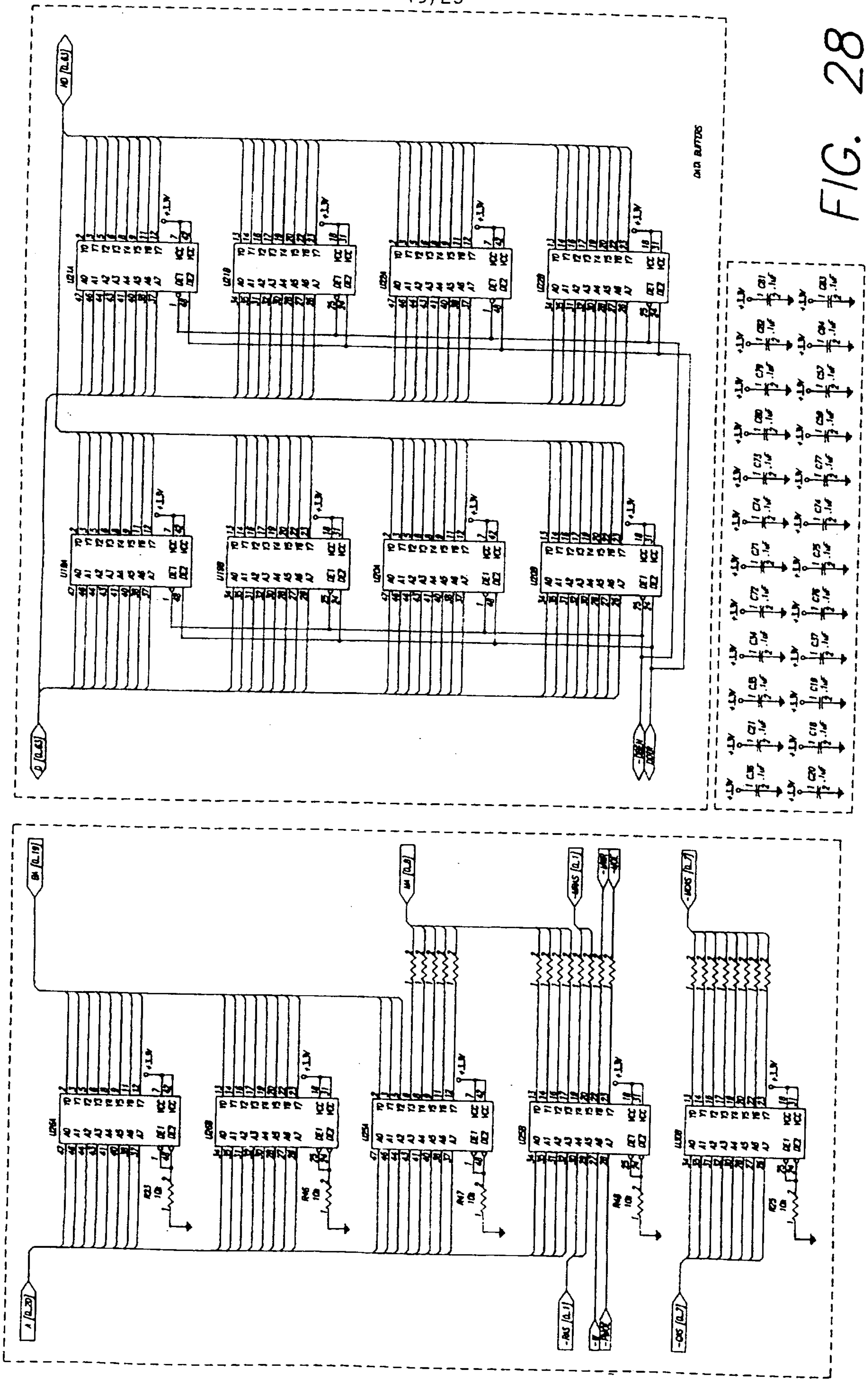


FIG. 28

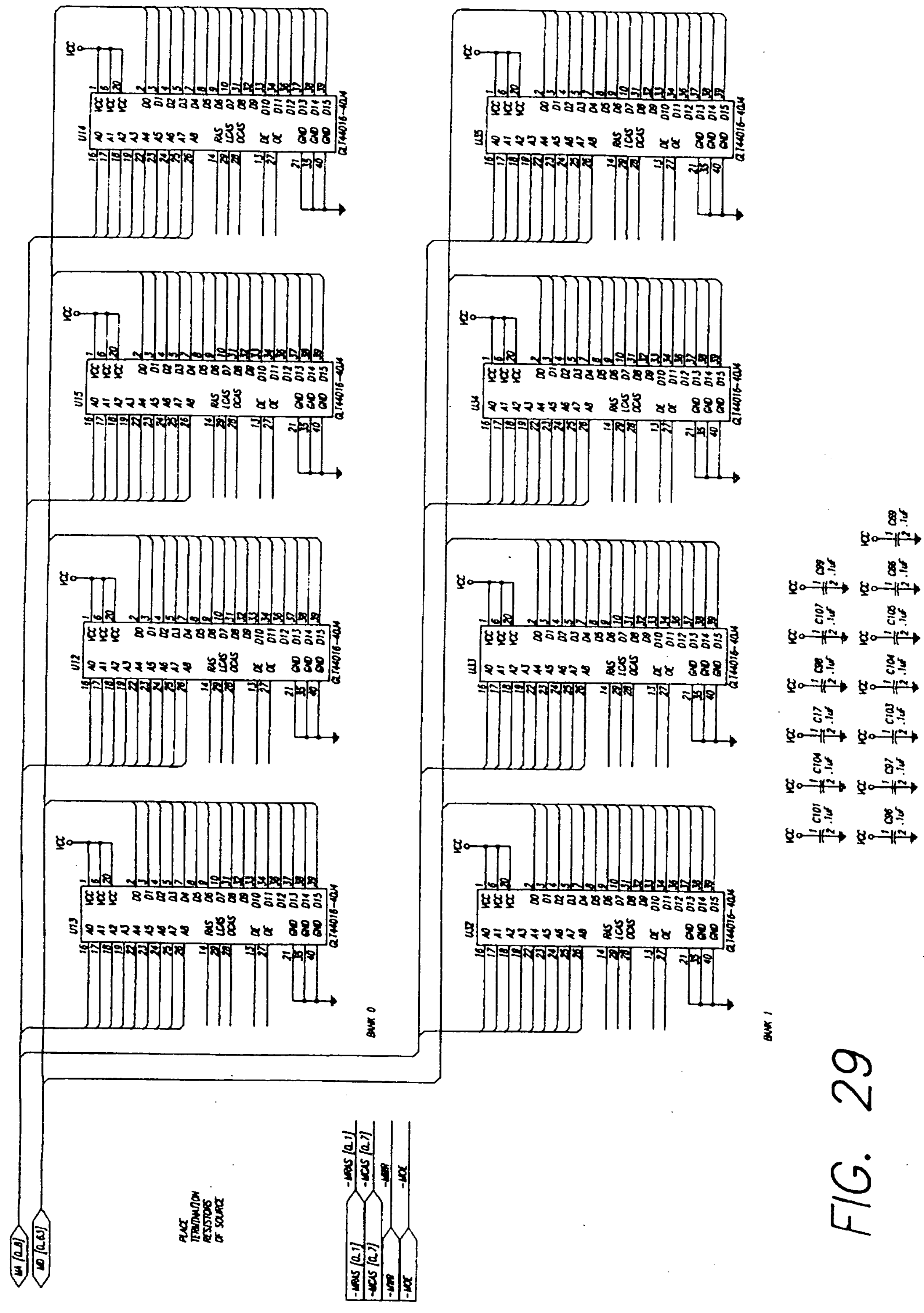


FIG. 29

FIG. 30

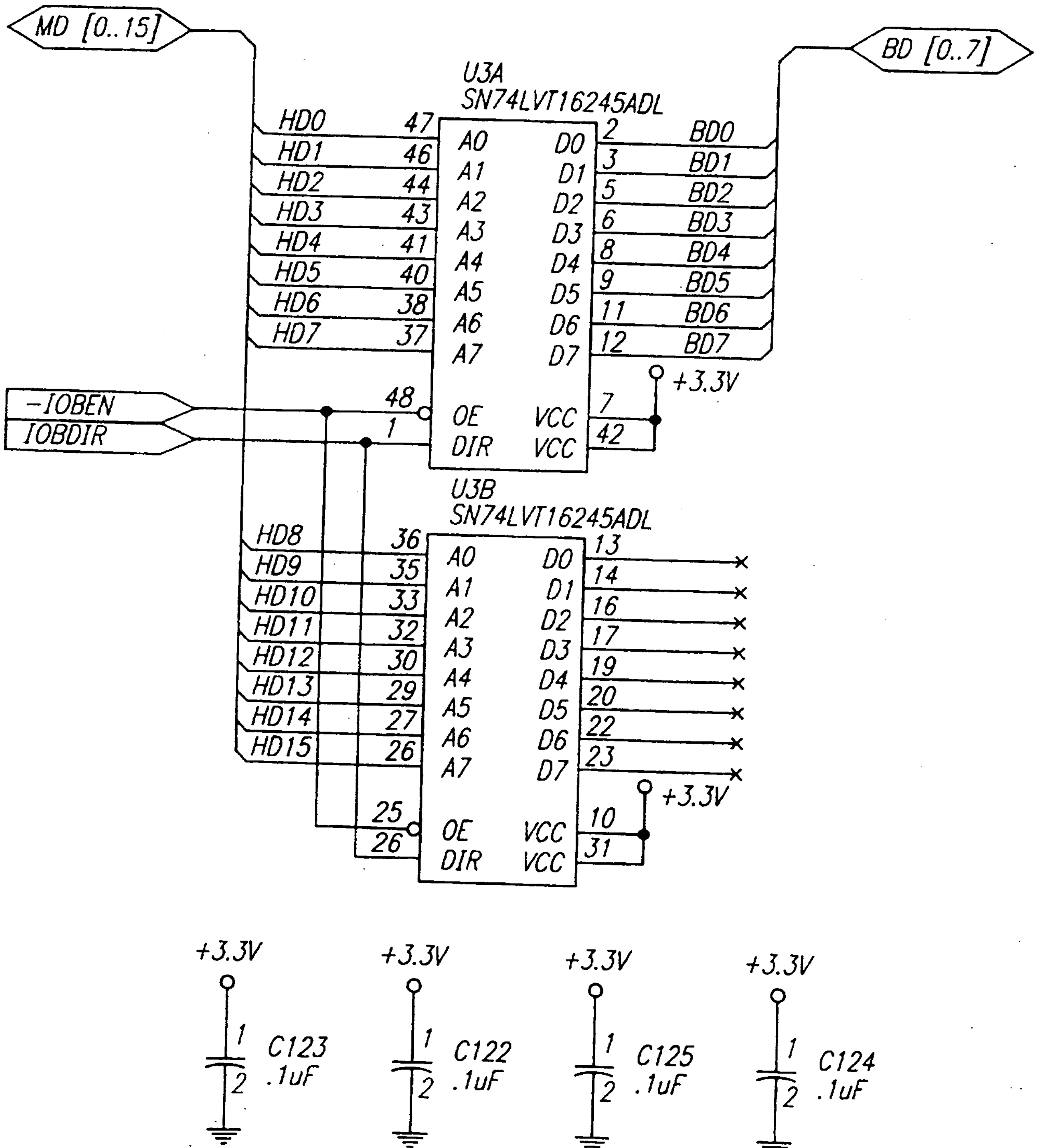
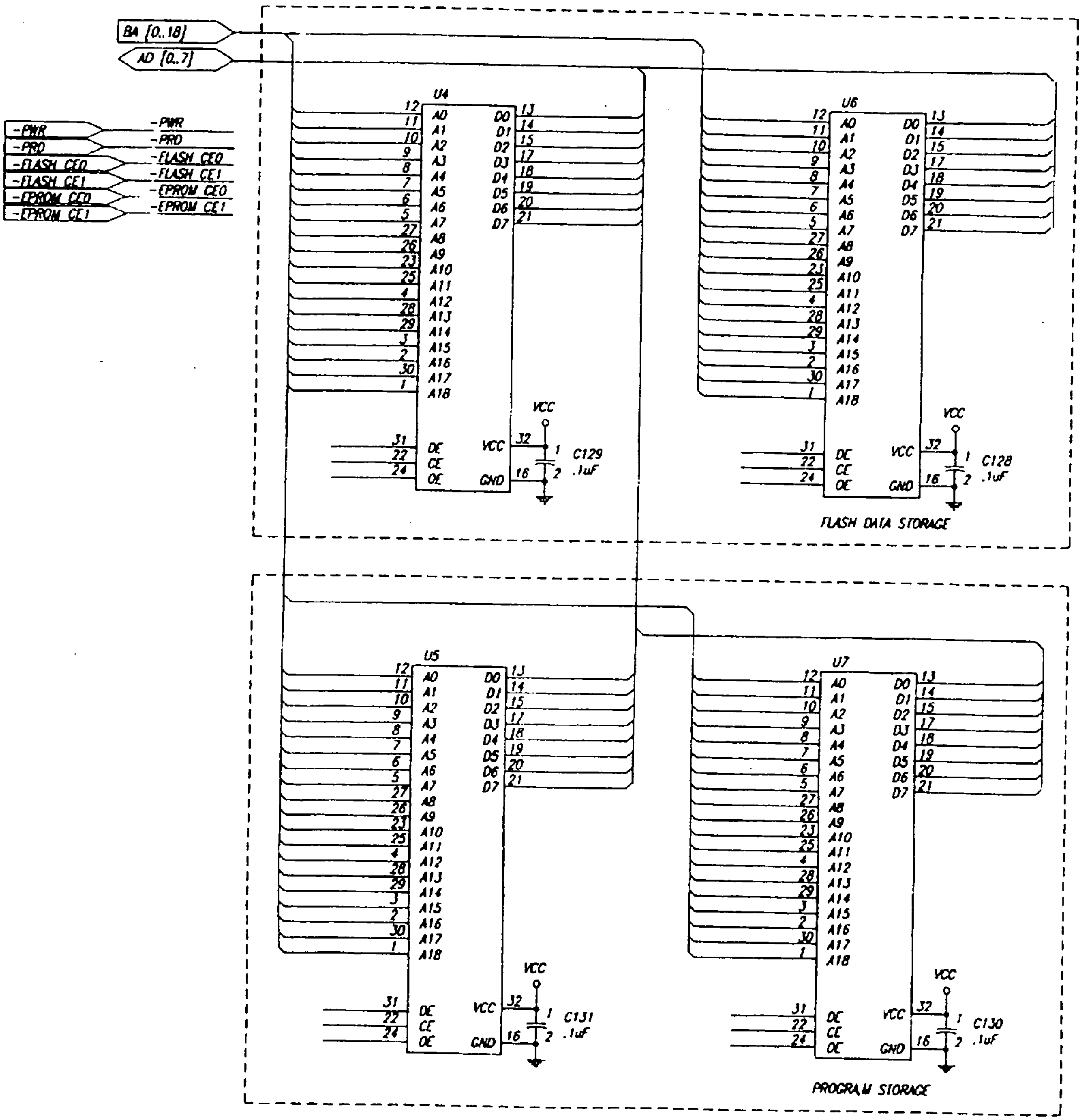

MD [0..15]
BD [0..7]
U3A
SN74LVT16245ADL
HD0
HD1
HD2
HD3
HD4
HD5
HD6
HD7
47
46
44
43
41
40
38
37
A0
A1
A2
A3
A4
A5
A6
A7
D0
D1
D2
D3
D4
D5
D6
D7
2
3
5
6
8
9
11
12
BD0
BD1
BD2
BD3
BD4
BD5
BD6
BD7
+3.3V
-IOBEN
IOBDIR
48
1
OE
DIR
VCC
VCC
7
42
U3B
SN74LVT16245ADL
HD8
HD9
HD10
HD11
HD12
HD13
HD14
HD15
36
35
33
32
30
29
27
26
A0
A1
A2
A3
A4
A5
A6
A7
D0
D1
D2
D3
D4
D5
D6
D7
13
14
16
17
19
20
22
23
+3.3V
25
26
OE
DIR
VCC
VCC
10
31
+3.3V
C123
.1uF
+3.3V
C122
.1uF
+3.3V
C125
.1uF
+3.3V
C124
.1uF

FIG. 31


BA [0..18]
AD [0..7]
-PWR
-PRD
-FLASH CE0
-FLASH CE1
-EPROM CE0
-EPROM CE1
U4
U6
U5
U7
VCC
C129 .1uF
C128 .1uF
C131 .1uF
C130 .1uF
FLASH DATA STORAGE
PROGRAM STORAGE

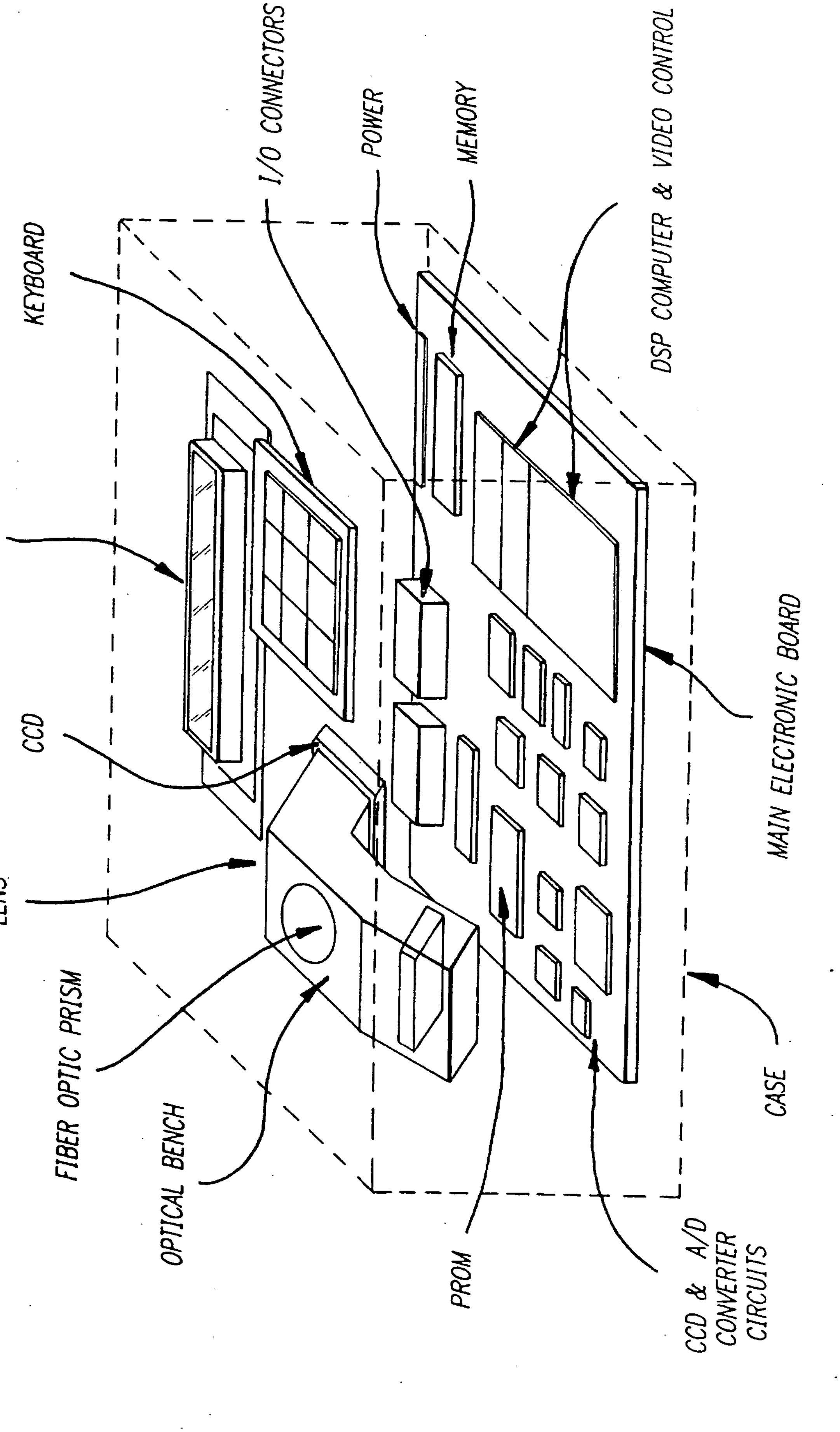

KEYBOARD
I/O CONNECTORS
POWER
MEMORY
DSP COMPUTER & VIDEO CONTROL
LCD DISPLAY
CCD
LENS
FIBER OPTIC PRISM
OPTICAL BENCH
PROM
CCD & A/D CONVERTER CIRCUITS
CASE
MAIN ELECTRONIC BOARD

FIG. 32

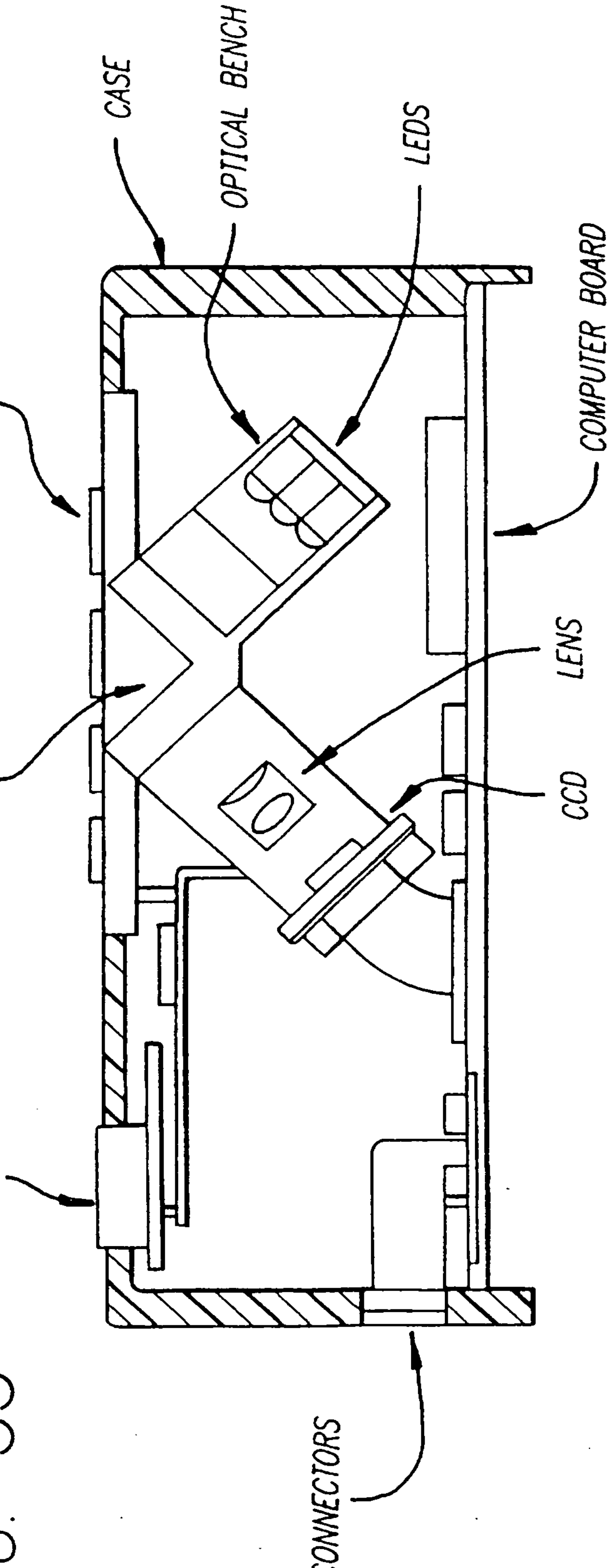

CASE
OPTICAL BENCH
LEDS
KEYBOARD
COMPUTER BOARD
FIBER OPTIC PRISM
LENS
CCD
LCD DISPLAY
CONNECTORS

FIG. 33

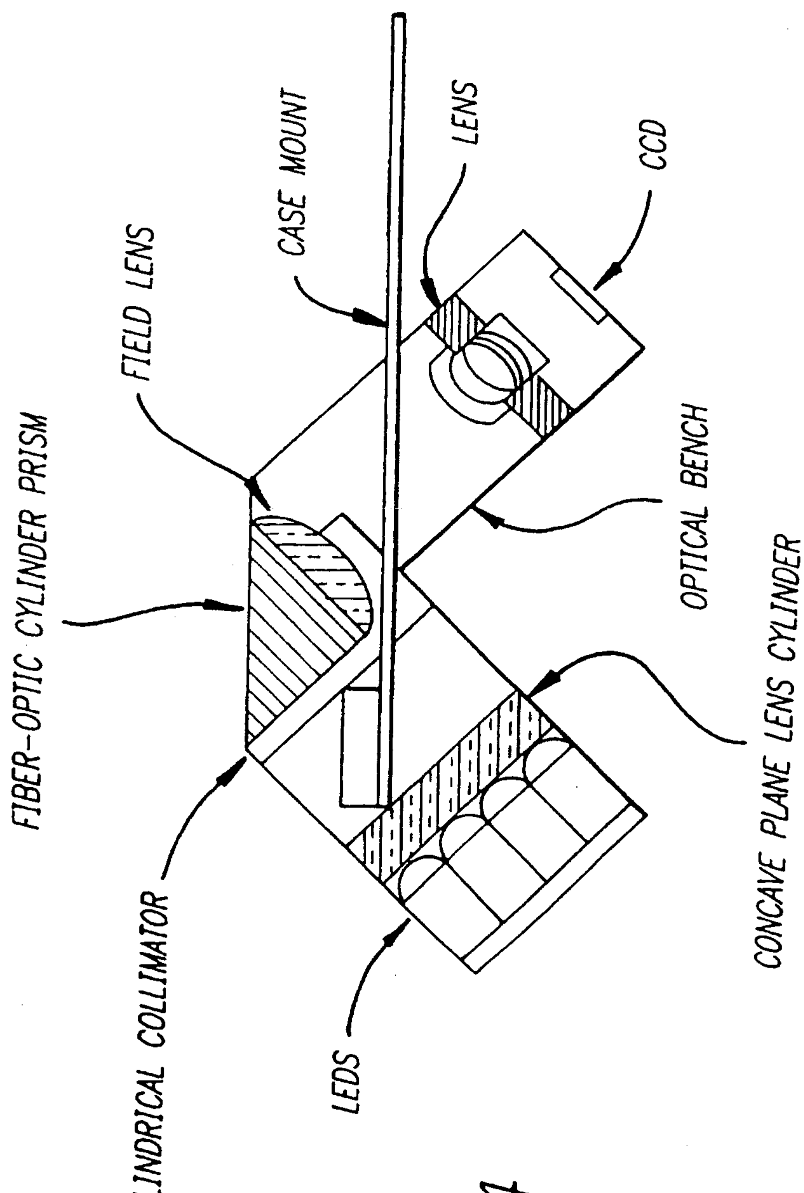

FIBER-OPTIC CYLINDER PRISM
FIELD LENS
CASE MOUNT
LENS
CCD
OPTICAL BENCH
CONCAVE PLANE LENS CYLINDER
CYLINDRICAL COLLIMATOR
LEDS

FIG. 34

PCT

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International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : **G06K 9/00, 9/74, G06F 7/04** A3

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(43) International Publication Date: 12 March 1998 (12.03.98)

(21) International Application Number: PCT/US97/16661

(22) International Filing Date: 9 September 1997 (09.09.97)

(30) Priority Data:
08/709,785 9 September 1996 (09.09.96) US

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(74) Agents: LIPPMAN, Peter, I. et al.; 4385 Ocean View Boulevard, Montrose, CA 91020 (US).

(81) Designated States: AM, AT, AU, BB, BG, BR, BY, CA, CH, CN, CZ, DE, DK, EE, ES, FI, GB, GE, HU, ID, IS, JP, KE, KG, KP, KR, KZ, LK, LR, LT, LU, LV, MD, MG, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TT, UA, UG, UZ, VN, ARIPO patent (GH, KE, LS, MW, SD, SZ, UG, ZW), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).

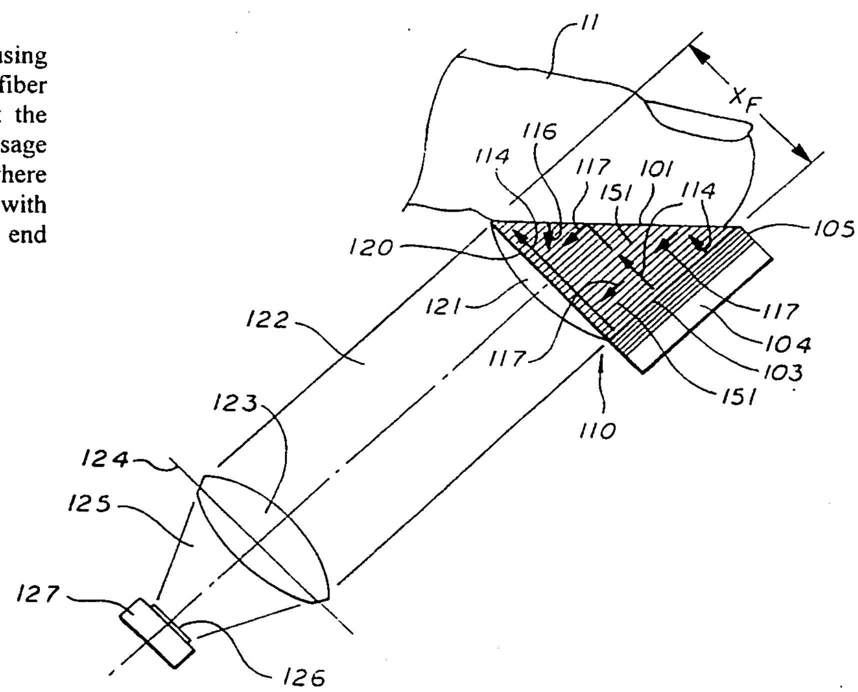
Published
With international search report.

(88) Date of publication of the international search report: 14 May 1998 (14.05.98)

(54) Title: ECONOMICAL SKIN-PATTERN-ACQUISITION APPARATUS FOR ACCESS CONTROL; SYSTEMS CONTROLLED THEREBY

(57) Abstract

Surface relief of a finger (11) is read using an optical-fiber prism unit (110), with fiber terminations at one end (101) to contact the surface, and at the other (120) for light passage along fibers from the first. Light enters where NA < 0.5 and fiber diameter is constant with longitudinal position, to light the first end terminations.



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SZ	Swaziland
TD	Chad
TG	Togo
TJ	Tajikistan
TM	Turkmenistan
TR	Turkey
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VN	Viet Nam
YU	Yugoslavia
ZW	Zimbabwe

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US97/16661

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :G06K 9/00, 9/74; G06F 7/04
US CL :382/115, 124, 127; 356/71; 340/825.31, 825.34
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : Please See Extra Sheet.

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS, MAYA, IEEE DATABASES
search terms: fingerprint, prism, fiber or fibre or waveguide

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,426,296 A (SHIKAI ET AL) 20 June 1995, abstract, figures 2-3, col. 8, lines 25-35, col. 14, lines 1-34, col. 9, lines 34-68.	1-3, 11-13, 18-19, 24-49
Y,E	US 5,684,906 A (SUGAWARA) 04 November 1997, abstract, figuer 4, col. 3, line 50 - col. 7, line 25, especially col. 5, lines 42-50.	1-3
Y	US 5,416,573 A (SARTOR, JR.) 16 May 1995, abstract, figure 3, col. 5, line 30 - col. 6, line 22, especially col. 5, lines 50-52.	1-3, 29-37
Y	US 5,146,102 A (HIGUCHI ET AL) 08 September 1992, abstract, figure 1 : 14, col. 7, lines 37-55, col. 9, lines 14-40.	26-28, 34-43
Y	US 5,426,708 A (HAMADA ET AL) 20 June 1995, abstract, figure 2, figure 1 : 4a.	45-49

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
13 JANUARY 1998	19 FEB 1998

Name and mailing address of the ISA/US	Authorized officer
Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	BHAVESH MEHTA
Facsimile No. (703) 305-3230	Telephone No. (703) 308-5246

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US97/16661

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,552,766 A (LEE ET AL) 03 September 1996, abstract, figures 4-5 & 9.	45-49
X --- Y	US 5,467,403 A (FISHBINE ET AL) 14 November 1995, abstract, figure 1, figure 5, col. 2, lines 7-15, col. 3, line18 - col. 8, line 17.	4-10,14-17, 20-23 -------------- 11-13, 18-19, 24-28
Y	US 5,448,649 A (CHEN ET AL) 05 September 1995, abstract, figures 2 & 4.	44
A	US 4,932,776 A (DOWLING, JR. ET AL) 12 June 1990, entire document.	1-49
A	US 5,548,394 A (GILES ET AL) 20 August 1996, abstract, figure 2.	1-49
A	US 5,103,486 A (GRIPPI) 07 April 1992, figures 3 & 5, col. 7, lines 40-55.	4-5, 11, 14-17

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US97/16661

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

Please See Extra Sheet.

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US97/16661

B. FIELDS SEARCHED
Minimum documentation searched
Classification System: U.S.

382/115, 116, 124, 126, 127; 356/71; 340/825.3, 825.31, 825.34; 235/380, 382, 382.5; 348/156; 902/3, 5, 6; 250/227.11, 227.2, 556

BOX II. OBSERVATIONS WHERE UNITY OF INVENTION WAS LACKING
This ISA found multiple inventions as follows:

This application contains the following inventions or groups of inventions which are not so linked as to form a single inventive concept under PCT Rule 13.1. In order for all inventions to be searched, the appropriate additional search fees must be paid.

Group I, claim(s)1-28, drawn to fingerprint identification.
Group II, claim(s) 29-37, drawn to optical fiber imager.
Group III, claim(s) 38-43, drawn to condenser lens.
Group IV, claim 44, drawn to a method for fabricating prisms.
Group V, claims 45-49, drawn to a combination of door handle and lock set.
The inventions listed as Groups I-V do not relate to a single inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons: the special technical feature of the Group I invention is the projection of light across the fibers in a region where numerical aperture is less than 0.5, the special technical feature of the Group II is the specific details of the optical-fiber prism, the special technical feature of the Group III is the specifics of the condenser lens, the special technical feature of the Group IV is the method for fabricating prisms and the special technical feature of the Group V is the combination of the door handle and the lock set. Since the special technical feature of any one of Groups I-V is not present in any of the remaining Groups I-V, unity of invention is lacking.